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THE ALPINE VEGETATION OF MARMOT BASIN, JASPER NATIONAL PARK, ALBERTA, AND THE IMPACT OF SKI ACTIVITIES UPON IT.

by

© EVELYN HOPE HAMILTON

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Alpine Vegetation of Marmot Basin, Jasper National Park, Alberta, and the impact of ski activities upon it submitted by Evelyn Hope Hamilton in partial fulfilment of the requirements for the degree of Master of Science in Plant Ecology.

ABSTRACT

The alpine vegetation of Marmot Basin, Jasper National Park, was sampled, analysed and classified into five main categories. Heath Tundra communities dominated by *Cassiope mertensiana* and *Phyllodoce glanduliflora* cover most of the well vegetated parts of this moderately late snow released cirque basin. Rock Tundra communities dominated by *Dryas octopetala* occur locally in xeric exposed sites that are snow free early in the summer. Shrub Tundra communities, which are dominated by several species of dwarf willows, are found in several types of relatively early snow released, more mesic sites. Meadow Tundra communities, in which mesophytic forbs are visually prominent occur in the protected, seepage sites and on the very sparsely vegetated scree slopes that cover almost half of the alpine zone. Snowbed Tundra communities are found in late snow released areas.

An analysis of the impact of winter ski activities on the snow pack, terrain and vegetation was carried out in a year of record low snowfall. Results indicate that the compaction of the snow on ski slopes by snow packing machinery and skiers results in significant changes in the density of the snow pack, which may alter the thermal regime of the underlying vegetation. It was found that skiers and snow packing machines sheared the snow off of thinly snow covered, convex sites, exposing the underlying vegetation and soil. Once exposed, the vegetation and upper layer of soil was often sheared off, leaving patches of bare soil that were susceptible to erosion. The removal of patches of snow cover led to the acceleration of snow melt.

Raised convex sites were the most susceptible to this type of damage. Once removed, the Rock Tundra vegetation which occurs in these areas is very slow to recover. Most of the other types of vegetation found at Marmot Basin naturally occur in sites which are less frequently damaged. In addition, most other types of vegetation are either more resistant to damage or regrow more rapidly if disturbed.

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CHAPTER I. INTRODUCTION

The increasing demand for expansion of downhill ski facilities in alpine areas has met with opposition from those who feel that these areas should be preserved in their natural state. Much of this debate has focused on the alpine zone. The superior snow conditions, scenery and relative ease of construction of ski runs in this treeless terrain make it ideal for skiing. However, the aesthetic appeal and documented sensitivity of this region to human impact make preservation of unaltered alpine ecosystems equally important.

Several studies have been carried out in North America and Europe to determine the environmental impacts of the construction and ongoing use of ski facilities. Several workers including Muir (1967), Leeson (1976b) and Fitzmartyn (1976a, 1976b) have described the impacts of the development and use of the Sunshine ski resort in Banff National Park, Alberta. Leeson (1976a) completed a preliminary investigation of the Marmot Basin ski area in Jasper National Park, Alberta, documenting the conditions found in this ski area. The impacts of the construction of ski facilities at Mission Ridge, Washington, were documented by Klock (1973). Graybeal (1973) described the changes that occurred in vegetation in subalpine areas at Winter Park Ski Area, Colorado.

Several workers including Bayfield (1970, 1974, 1976) and Watson *et al.* (1970) examined the impacts of ski area construction and ongoing use at Cairngorm, Scotland. In Austria, a team of researchers has been studying the alpine ecosystem at Obergurgl (Himamowa 1975).

This information on the general impacts of ski area construction and ongoing use of the vegetation found in these selected areas can be used along with information on the types of vegetation found in alpine areas to make predictions of the impacts of ski activities. The nature of the vegetation in alpine areas in western Canada and the United States has been described by a series of researchers. Studies of the alpine vegetation of Signal Mountain (Hrapko 1970 , Hrapko and La Roi 1978), Bald Hills (Kuchar 1975) and Wilcox Pass (Crack 1977) in Jasper National Park; Snow Creek Valley (Beder 1967), Bow Pass (Broad 1973) and Sunshine (Knapik *et al.* 1973) in Banff National Park; Prospect Mountain (Mortimer 1978) and Highwood Pass (Trottier 1972) in the Front Range have been made in recent years. Studies of the alpine vegetation of British Columbia have been made by Archer (1963), Brink (1964), Brooke *et al.*(1965) and Eady (1971), while in the U.S., work has been done in the alpine of Washington by Franklin *et al.* (1971) and Douglas and Bliss (1977).

The objectives of this study were to:

1. describe and classify the vegetation of the alpine zone of Marmot Basin, Jasper National Park;
2. determine the general impacts of winter ski activities (snow compaction and downhill skiing) on the snow cover, vegetation and terrain;

3. evaluate the susceptibility of alpine vegetation to these impacts;
4. make recommendations for future management of alpine ski areas.

CHAPTER II. STUDY AREA

LOCATION

Marmot Mountain is located in the Main Range of the Rocky Mountains, 21 km south of Jasper townsite, in Jasper National Park, Alberta (Fig. 1 & 2). The mountain is surrounded by three rivers; the Athabasca River to the east, Portal Creek to the south, and Whistlers Creek to the north (Fig. 2).

DESCRIPTION

Marmot Basin is situated in a cirque on the east side of the upper section of Marmot Mountain (Fig. 3). The base of the Basin is 1950 m above sea level (ASL) and extends to the summit of Marmot Mountain at 2605 m. The cirque faces NE; it is bounded on the S and SE by Eagle Ridge, to the W by the summit ridge of the mountain, and to the NW by Caribou Ridge. The main cirque consists of several basins: a small one in the centre surrounded by scree slopes, a large V-shaped hollow to the S, and a third shallow basin at about 2400 m at the W end of the main basin. These three basins are separated by Knob Hill and the ridge that runs SE from it (Fig. 3).

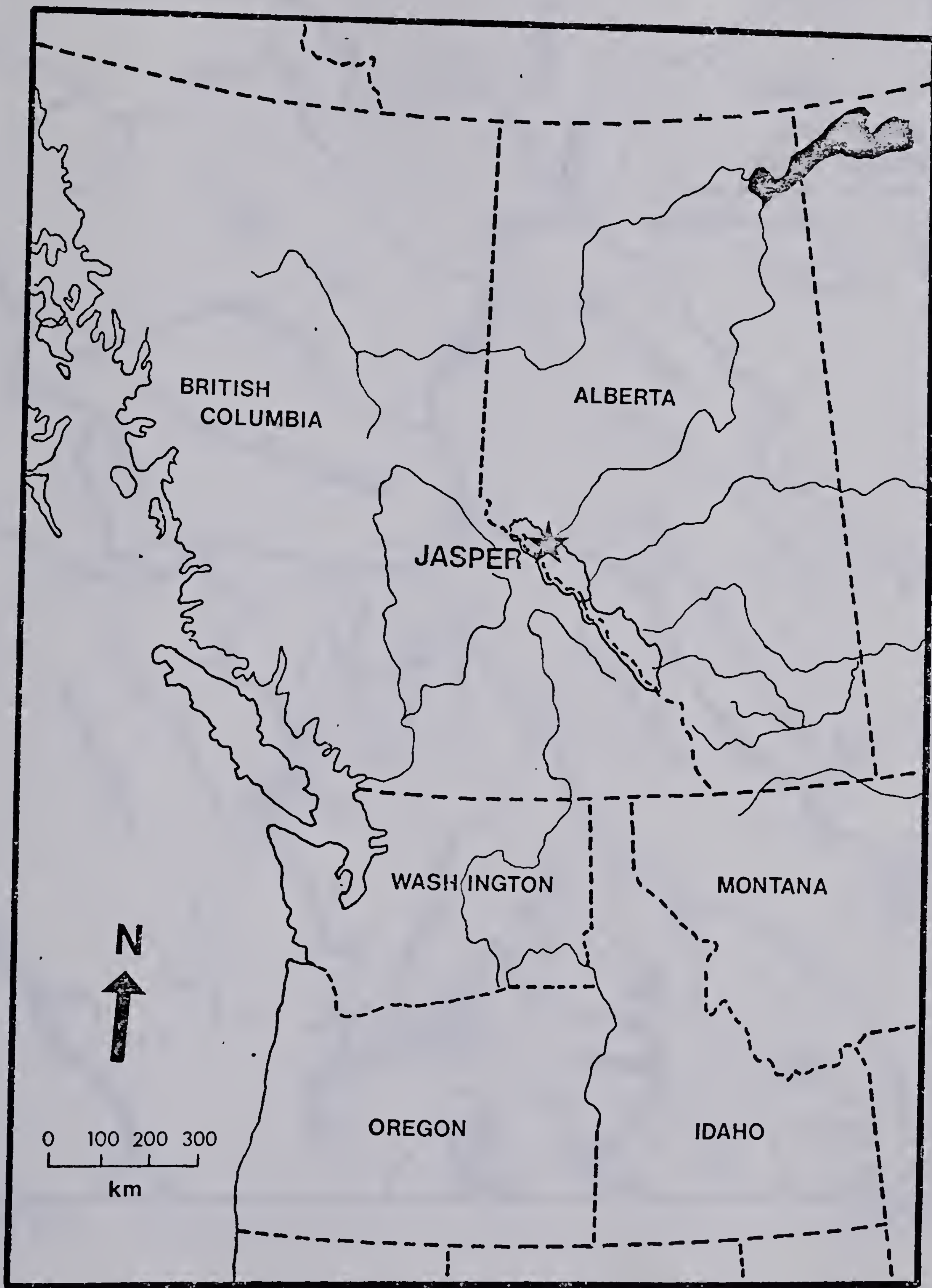


Fig. 1. Map of Alberta, British Columbia and the northwestern United States.

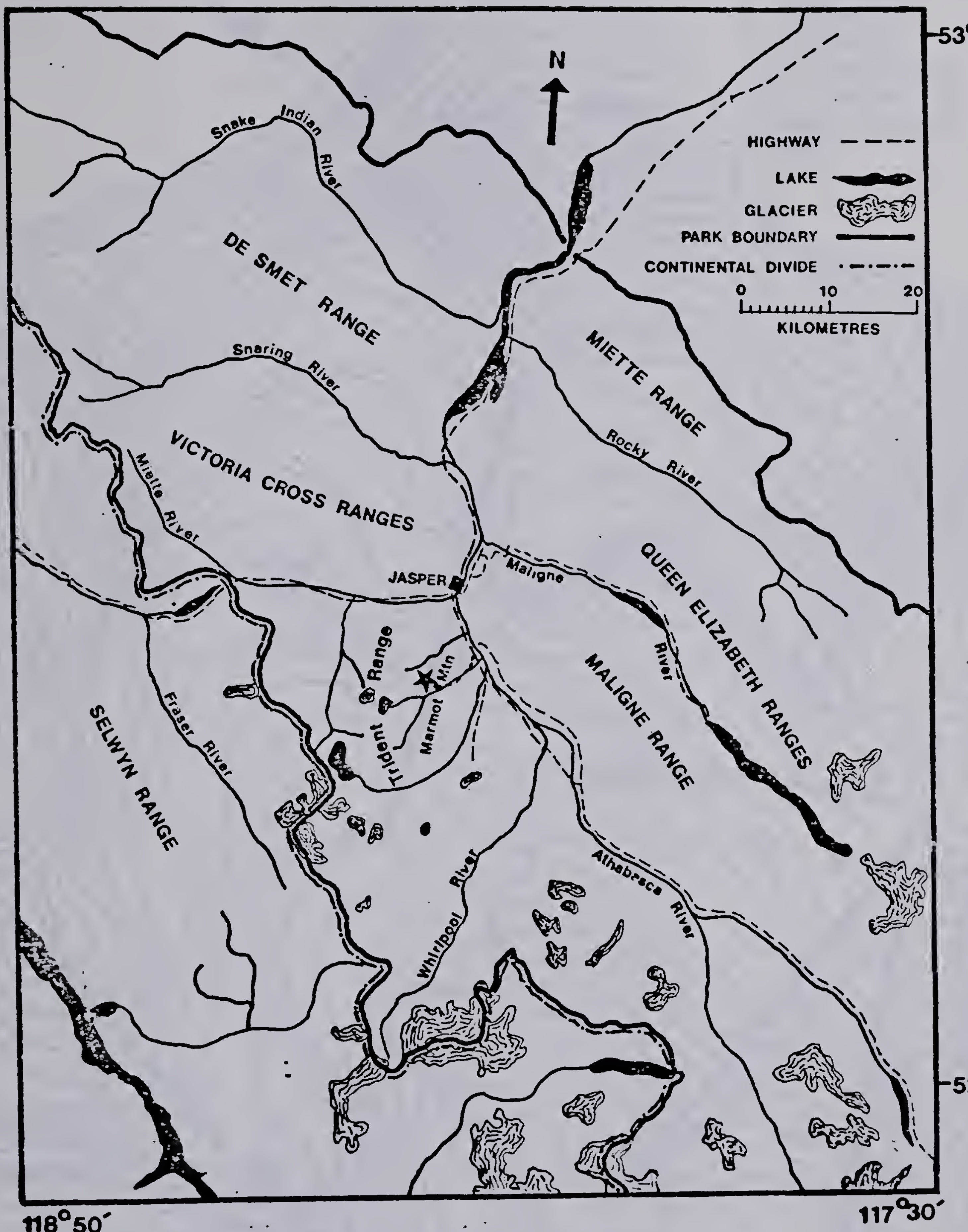


Fig. 2. Map of the central region of Jasper National Park, Alberta. Star shows location of Marmot Basin. (See Fig. 3 and Plate 21, p 106 for details of access road to Marmot Basin.)

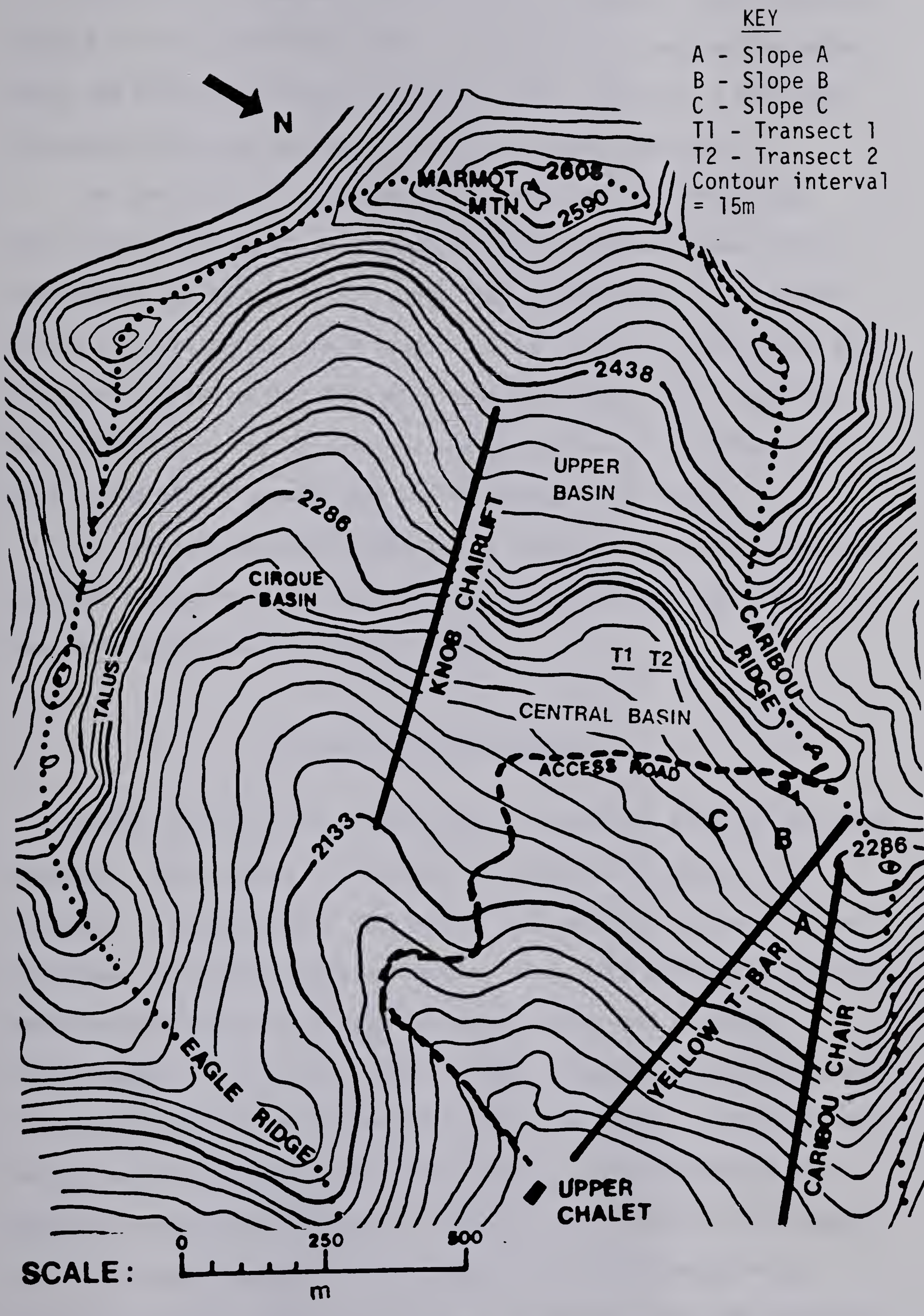


Fig. 3. Contour map of Marmot Basin, Jasper National Park.

Ski lifts and terminal buildings are situated on Knob Hill and on Slope A at the N end of the basin. Two lifts are found on the latter site, the Caribou Chair and the Yellow T-bar. There is a road from the upper chalet to the top of the Yellow T-bar (Plate 1).

The lower half of the basin is in the subalpine forest zone. *Picea engelmanii* and *Abies lasiocarpa* are the dominant tree species with heaths and shrubs in the understory. Continuous forest grades upward into scattered tree islands at about 2100 m. Krummholz is also found on wind-protected sites at higher elevation. Dwarf heath tundra dominated by *Cassiope mertensiana* and *Phyllodoce glanduliflora* covers most of the alpine area of the basin accessible to skiers.

Ski runs originating in the alpine tundra section extend downward into the subalpine forest section of the basin, where tree removal has been undertaken (see Plate 21, p. 106).

GEOLOGY AND GEOMORPHOLOGY

Marmot is part of the Trident Range of the Main Range of the Rocky Mountains. The bedrock is Pre-Cambrian aged Wynd Formation. This formation is approximately 1200 m thick and consists of poorly sorted arenaceous and argillaceous sedimentary rock. The former are primarily sandstone and conglomerate and the latter slates and siltstones (Charlesworth *et al.* 1967). The basin was formed by frost wedging of the exposed edge of the upthrust bedrock. The absence of terminal or lateral moraines indicate that the basin was probably occupied by a snowfield rather than a glacier. The SE, S and W walls of the cirque are talus slopes composed of rock debris continually produced by erosion of cliffs. Finer materials are carried downslope by snowmelt

Plate 1. The alpine vegetation of Marmot Basin, viewed from Eagle Ridge. Heath Tundra communities, which are a dark green colour, cover most of the alpine terrain. Meadow Tundra, which is a lighter green, is found in the center of the photo. Snowbed Tundra communities, which have a gold colour, occur in the shallow basin in the upper left corner of the photo. Rock Tundra communities are found on the exposed ridges; these are grey-green in colour.

and rainwaters and deposited in the more gently sloping parts of the basin. Solifluction lobes are found on the steeper vegetated slopes. (Leeson 1976a).

HISTORY OF SKI DEVELOPMENT

The alpine zone of Marmot Basin has been used for skiing since the 1930s. In the early days snowmobiles were used to drive skiers to the top of Slope A (Fig. 3). In 1964 a road and the first lift, the Yellow T-bar, were built to the top of slope A. The second lift, the Yellow Chair, was built in the lower section of the basin in 1969, followed by the Caribou Chair, built in 1973 and the Knob Chair, built in the alpine in 1977.

CHAPTER III. METHODS

PHYSICAL ENVIRONMENT

CLIMATE

A meteorological station was set up at 2220 m ASL on an E-facing slope on Caribou Ridge (Fig. 3). The station consisted of a louvered aluminum shelter set on the ground which contained a Belfort hygrothermograph with sensors 2 to 15 cm above the ground and a Taylor Maximum-Minimum thermometer shielded with sensors 3 cm above the ground surface. A Belfort actinograph was positioned on top of the shelter. A three-cup totalizing Belfort anemometer with cups 1 m above the ground and a 20 cm wedge rain gauge with orifice 50 cm above the ground were situated nearby. The station was monitored from 5 May to 8 August 1977. Maximum and minimum temperatures, precipitation and total kilometers of wind were recorded every second day at 1000 h MDT. The hygrothermograph was calibrated at these times using a Taylor sling psychrometer.

SOILS

Soil pits were dug in the 10 plant communities which were regarded as representing the range of communities found in Marmot Basin. Soils

were classified, their horizons delimited and thickness measured and rooting depths determined. Samples of each horizon were taken in mid-August. These samples were air dried and passed through a 2 mm sieve to determine coarse fraction content. Further analysis of the <2mm fraction was then carried out. Dried soil colour was determined under natural daylight using Munsell colour charts. The Bouyoucos (1962) hydrometer method was used to determine soil texture. Soil pH, conductivity, % organic matter, free lime content and N, P, K and Na concentrations were determined by the Alberta Soil and Feeding Testing Lab.

Soil pH and conductivity were determined using a 1:2 soil:water ratio with conductivity correlated back to paste equivalent. Organic matter was estimated. Available potassium and sodium were determined by extraction with 1N NH_4OA_C. The extract was mixed with lithium as an internal standard and concentration read using the flame photometer. Nitrate nitrogen (N) and phosphorous were extracted using 0.03N NH_4F and 0.03N H_2SO_4 (Miller and Axley method). The Technical Industrial Method No. 100-70W (1973) was used to analyse for NO_3 and NO_2. Phosphate was determined using the Murphy and Riley (1962) method. Sulphate-sulphur was determined through extraction with 0.1M $CaCl_2$ distilled with Deans modification of Johnson-Nishita method and read on the Spectronic 20. Available Al and Mn were determined by extraction with 0.02M $CaCl_2$ and read on the atomic absorption spectrophotometer. Exchangeable cations were determined through leaching with CH_3COONH_4. Cation exchange capacity (C.E.C.) was calculated by leaching with C_2H_5OH and CH_3COONa and distillation with MgO. (Alberta Soil and Feed Testing Lab 1977).

VEGETATION ANALYSIS

COMMUNITY DESCRIPTIONS

The plant communities of Marmot Basin were delimited using air photos and ground surveys. Thirty-seven stands that had homogeneous plant cover and which represented the range of plant communities found in the study area were sampled. Stands were from 10 x 4 to 10 x 20 m in size; twenty 25 x 25 cm quadrats were set out randomly in each stand. In some of the small and very homogeneous stands only 15 quadrats were used. The Braun-Blanquet cover scale[1] was used to visually estimate the cover of the vascular plant species, lichens, bryophytes, and bare rock and soil in each quadrat. A ten point frame was used to verify these estimates. Notes on slope angle and exposure, elevation and landform type were made and photographs of the sites were taken. Voucher specimens of vascular plants were collected from the plots sampled. Nomenclature follows Moss (1959) and Hultén (1968). Speciments were verified by Dr. J.G. Packer and are deposited in the University of Alberta Herbarium (ALTA).

TRANSECT STUDIES

Two transects were run from the center of nivation hollows to the top of the surrounding slopes. Both transects were located in the center of the main cirque basin at 2240 m elevation. Transect 1

---

[1] + = <1%, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-100% cover.

traversed the range of plant communities found on a N-facing slope; Transect 2 was located on the S-facing wall of an adjoining snowbed (Fig. 3).

The transects were 16 m long; 25 x 25 cm quadrats were set out at 75 cm intervals along the transect. The Braun-Blanquet cover-abundance scale was used to determine the cover of the vascular plant species, lichens, bryophytes and bare rock and soil in the quadrats. Photographs of the whole transects and of individual quadrats were taken.

ORDINATIONS

Two types of ordinations were used in the analysis of the stand data and the classification of plant communities. Both ordinations, the Bray-Curtis indirect and Reciprocal Averaging were based on species prominence values (P.V.s). To calculate P.V.s, the mean percent cover and quadrat frequency of 56 vascular plant species found in stands sampled were first determined. Species which had low cover and occurred in only one of the 37 stands and species which did not have more than 0.01% cover in any stand were excluded from the ordination. Prominence Values for the 56 species were determined using the formula:

$$\text{P.V.} = \text{mean cover \%} \times \sqrt{\text{frequency \%}}$$

Bray-Curtis Ordination

Two types of stand similarity matrices, one based on presence--absence data and the other on quantitative data were calculated using the Cornell Ecology Program (Gauch 1973). This program was used to calculate similarity matrices for the 37 stands, using the P.V.s of

vascular plant species. The first matrix was a Coefficient of Community (CC) index based on presence-absence data and the second matrix was a Percentage Similarity (PS) index based on species P.V.s. These similarity matrices were used to determine the endpoints for the two Bray-Curtis ordinations which were then calculated using the Cornell Program. The matrices were used to select two stands which showed little similarity to each other to be used as the X axis endpoints. Ordination of the stands using these endpoints generated a one-dimensional array of stands. The distance between a stand and an endpoint reflects the similarity of the two stands. Another pair of stands which were close together on the X axis but showed little similarity to each other were selected for the Y axis endpoints and used to calculate the Y axis ordination. The positions of stands along the two axes are used as coordinates in the two-dimensional plotting of stands.

Reciprocal Averaging Ordination

Species-stand tables were obtained using an indirect, weighted average Reciprocal Averaging program (Hill 1973, Gauch *et al.* 1977). This program uses successive approximations to produce a simultaneous one-dimensional species and stand ordination.

VEGETATION MAP

A map of the vegetation of the alpine zone of Marmot Basin was made using aerial photographs and information obtained from community analysis. Map units included plant communities, community groups and mosaics of several communities in areas where plant communities were too small to be mapped separately.

IMPACT ASSESSMENT

A series of investigations was carried out to determine: 1) the impact of construction of ski facilities, and 2) the impact of winter ski activities on the snow cover, vegetation and terrain of Marmot Basin. Observations were made assessing the alterations in the natural environment which had occurred as a result of the construction of ski lifts, roads and buildings.

More intensive studies were carried out to determine the effects of winter ski activities including slope maintenance and skier use. Sampling was carried out along a series of transects which traversed the skied and non-skied sections of Slope A, B and C (Fig. 3). Snow cores, used to determine the effect of ski activities on the depth and density of the snow were taken along the transects on Slope C in March and May 1977. In July 567 1 x 1 m plots were set out along transects on all three slopes and used to evaluate how severely the terrain underlying the skied slopes had been sheared. These plots were also used to determine: 1) the cover of vascular plant species using the Braun-Blanquet cover scale, and 2) the phenological status and vigour of *Cassiope mertensiand*, the most prominent heath species in the study area.

IMPACT OF CONSTRUCTION

Descriptions of the alterations to the natural environment which occurred as a result of the construction of ski facilities in the

alpine zone of Marmot Basin were made. Assessments of the extent and location of damaged terrain along roadways and in the vicinity of the ski lift towers and terminal buildings were made. Evaluations of the severity of erosion in these sites were also made. Comparisons of the impacts of construction on the alpine and subalpine zone were made. Evaluations of the type and extent of damage associated with helicopter-aided construction, and ground access construction were also made.

IMPACT OF WINTER SKI ACTIVITIES

Impact of Snow Compaction

Snowpack

A preliminary assessment of the depth and density and general condition of snow on the skied and non-skied sides of Slope C was made in March 1977 (Fig. 3). Four transects were set out across this slope; snow depths were recorded and duplicate snow cores taken for snow density determinations. Assessments of the prominence of ice layers in the snowpack were also made. Snow cores were taken at 10 m intervals along the four transects, using a Stevens Snow Sampling set. These data were used to calculate snow density and water content. Comparison of the snowpack on skied and non-skied slopes was carried out in May 1977. In May, fourteen transects were laid out in an E to W direction across Slope C. Snow cores were taken in a total of 102 sites, at 10 m intervals along these transects. A t-test was performed to determine if there was a significant difference between the depth, density and water content of the snow on the skied *vs* non-skied sides of this slope.

Correlations were calculated to determine if there was a relationship between snow depth and density.

A study was carried out to determine if there was a difference in the temperature of the soil-snow interface beneath compacted and non--packed snow on 2 March 1977. Snow pits were dug at 7 points along a transect. Soil temperatures were taken using a mercury thermometer. These data were used, along with information on the depth and density of the overlying snow, to determine if compaction of the snow had an appreciable effect on the thermal regime of the underlying soil.

Photographs of the study area were taken at 1 - 2 week intervals from 4 May - 8 August, 1977 to monitor snowmelt patterns. One series of photos was taken from the upper ski chalet during May. A second series was taken during June, July and August from a site on the top of Eagle Ridge (Fig. 2). These photos were used to determine if there was an appreciable difference between snowmelt patterns on skied *vs* non-skied terrain. Observations were also made and pictures taken in the following spring (29 April 1978) to determine if the patterns found in 1977 were typical or a result of unusual weather conditions which occurred during the preceding winter.

Vegetation

An evaluation of the vitality of *Cassiope mertensiana* plants found on the skied and non-skied sides of Slope C was made. Estimates of the ratio of the live to dead *Cassiope mertensiana* foliage were used as an indicator of plant vitality. The Braun-Blanquet cover scale was used to estimate the cover of dead and live *C. mertensiana* in 64 1 x 1 m plots set at 10 m intervals along 14 transects which traversed

the skied and non-skied sides of Slope C. The percentage of the dead *C. mertensiana* in a plot was calculated.

This information was used along with data on the depth and density of the overlying snow cover during May of the preceding spring to determine if there was any relationship between the vitality of the *Cassiope mertensiana* plants and the depth or density of the overlying snow.

Evaluations of the phenological stage(s) of *C. mertensiana* were also made in the 1 x 1 m plots. The *C. mertensiana* plants examined were classified as (1) pre-budding, (2) budding, (3) flowering and/or (4) setting seed.

Impact of Shearing

Snowpack

The results of the photo series (described on p. 116) were used to determine if the shearing of patches of the snow cover by skiers and machinery had a significant effect on the meltout patterns found on skied compared with non-skied slopes.

Terrain

The extent and type of damaged terrain in the 567 1 x 1 m plots set out on Slopes A, B and C was assessed using the Braun-Blanquet cover scale. Microtopography, slope angle, slope aspect and elevation were assessed at each sampling site. The percent cover of damaged ground classified as "surficially sheared," "churned" and "eroded" was assessed. Sites in which only the plant cover had been scraped off,

such that the upper soil surface was basically intact were classified as "surficially sheared." In "churned" areas the upper soil layer had been removed and cryoturbation had occurred; the soil in these areas was susceptible to erosion. Sites in which much of the humus and mineral fines of the A horizon had been washed away leaving only the coarse soil fraction were classified as "eroded." Once the vegetative cover has been sheared off the soil is subjected to cryoturbation and subsequent erosion by meltwater, wind and rain. The data were analysed to determine if there were correlations between the type of terrain and the severity of impact found in a site.

Calculations of the number of damaged plots in sites that were convex, concave and flat were made. Comparison of the numbers (frequency) of damaged plots on concave sites on Slopes A, B, and C were also made. The total areal extent of damaged ground in the concave sites was determined. Calculations were made to determine how much of the convex terrain on Slopes A, B and C was "eroded," "churned," "surficially sheared" or "regrown."

Vegetation

Estimates of the cover of the vascular plant species in 223 1 x 1 m plots on transects on Slope A were made. These data were used in calculating a reciprocal averaging ordination (see p. 39). Identification of the plots to plant community types was then carried out. The type of terrain and amount of disturbed terrain in each plot was also plotted on the ordination to determine if correlations between these factors and the type of plant community found in an area existed.

The information obtained from the previously described studies of the vitality and phenological status of *Cassiope mertensiana* on Slope A was used along with information obtained from sampling on Slope B and C to determine whether the shearing of the snow cover on skied slopes had a significant effect on *Cassiope mertensiana* populations.

Permanent 1 x 1 m plots were set out in 10 sites sampled on Slopes A, B and C. Photographs and assessments of the impact on the terrain, cover of vascular plant species and the vigour of *Cassiope mertensiana* plots were made on 7 June 1977 and again on 8 August 1977. These sites were re-examined in August 1978 to determine if any appreciable changes (e.g., regrowth or erosion) had occurred. Assessments of the success of various species in revegetating the sheared plots were also made.

CHAPTER IV. RESULTS: PHYSICAL ENVIRONMENT

CLIMATE

The climate of Jasper can be described as continental. There is a high degree of variability in seasonal and annual temperatures and precipitation, with wide deviations from average conditions. This area is under the ameliorative influence of Pacific air from the west. Only during the winter does this Pacific flow give way to Arctic air with the passage of the Arctic front resulting in precipitation and colder temperatures. Thus the winters can be long and quite cold with summers that are short and cool (Janz and Storr 1977).

The climatic data that had been collected at Marmot Basin over the past 10 years was used to describe "average conditions." Comparisons of the climatic conditions found in 1976-77 with those previously found at Marmot were made to determine if this year had been a representative one.

TEMPERATURE

Mean monthly temparatures in Marmot follow a trend similar to that found in Jasper townsite but are 2° to 7° C cooler (Table 1).

Table 1. Mean monthly temperature and snowfall in Jasper and Marmot Basin.

	N	D	J	F	M	A	M	J	J	A	S	O
					Mean monthly temperature (°C)							
Jasper 1941-75[1]	-3.0	-8.9	-12.2	-6.7	-2.8	+3.3	+8.9	+12.8	+15.0	+13.9	+10.0	+5.0
Marmot Basin 1965-76[1]	-9.2	-9.8	-12.5	-8.9	-8.4	-3.7	+0.1	-	-	-	-	-
Marmot Basin 1976-77[1] [2]	-8.8	-5.5	- 9.9	-5.8	-8.5	-1.7	+3.0	+6.3	+7.8	+5.9	-	-
					Mean monthly snowfall (cm)							
Jasper 1941-70[1]	32	33	30	24	15	23	-	-	-	-	-	-
Marmot Basin 1965-76[1]	100	77	109	74	71	75	-	-	-	-	-	-
Marmot Basin 1974-75[1]	67	41	38	52	50	12	-	-	-	-	-	-
Marmot Basin 1975-76[1]	23	85	66	80	66	17	-	-	-	-	-	-
Marmot Basin 1976-77[1] [3]	35	97	29	20	91	26	10	+	+	-	-	-
Marmot Basin 1977-78[1]	32	65	48	9	42	74	-	-	-	-	-	-

- no data + trace [1]sensors 1.5 m above the ground (Atmospheric Environment Service 1964-78a)
[2]sensors 15 cm above the ground [3]sensors 50 cm above the ground.

Table 2. Average yearly snowfall and spring snow cover depth in Marmot Basin.

	1964-65	65-66	66-67	67-68	68-69	69-70	70-71	71-72	72-73	73-74	74-75	75-76	76-77	77-78
Snowfall (cm)	444	632	487	518	505	337	495	454	439	447	261	346	298	270
Snow depth on May 1 (cm)	-	-	-	-	-	-	125	-	100	94	86	100	46	84

- no data Source: Atmospheric Environment Service (1964-78b)

Coldest mean monthly temperatures occur in January, usually close to $-12^{\circ}C$ in both Marmot Basin and in Jasper; warmest temperatures are in July, $8^{\circ}C$ in Marmot and $15^{\circ}C$ in Jasper. The difference between mean maximum and mean minimum monthly temperatures was $38^{\circ}C$ in the winter and $23^{\circ}C$ in the summer of 1976-77.

Mean monthly temperatures in Marmot Basin in the 1976-77 winter season were 2° to $4^{\circ}C$ warmer than the 1965-76 mean monthly temperature (Table 1).

PRECIPITATION

The precipitation regime of Marmot Basin and Jasper is marked by a high degree of annual variability. In some years there is 2.5 times as much precipitation as in other years. Marmot Basin, being at higher elevation, receives more precipitation than Jasper, especially in autumn and late spring. Annual precipitation at Jasper averages 402 mm.

Maximum precipitation occurs in December and January and the minimum in late spring and autumn. There is a weak secondary maximum in the summer. Light snow and rainfall are frequent with heavy precipitation rare (Janz and Storr 1977).

Snowfall patterns in Marmot Basin are similar to those in Jasper townsite although total snowfall is much less in the latter. The 5 year average snowfall in water equivalent units was 72 cm in Marmot Basin; the 11 year average for Jasper was 37 cm of water (Wells *et al.* 1976). Snowfall is variable, in some years there is 2 - 3 times as much snow as other years (Table 2). Average snowfall is 475 cm; much of it

falling in January. Total snowfall in 1976-77 and in the preceding two winters was 261-348 cm, which is lower than normal. In addition, the snowfall in 1976-77 was very irregular; much of the snow fell in December and March, with little snowfall in January, February and April. April snowfall in the two preceding years (1975-76 and 1974-75) had also been light (Atmospheric Environment Service 1969-78).

Maximum snowpack at high elevations such as Marmot occurs in April, much later than the maximum snowpack at Jasper. In years of average snowfall there was 86 to 125 cm snow base on the ground at approximately 2340 m elevation in April. In 1976-77, snowfall was light and there was only 46 cm of snow on the ground at this elevation in April 1977 (Atmospheric Environment Service 1969-78).

SUMMER CONDITIONS

Records of the summer weather conditions at Marmot Basin are, unfortunately, only available for May - August 1977 (Fig. 4-7), since the recording station is shut down during the summer and early fall.

Temperature

The average daily temperature in May 1977 was 3°C (Fig. 4). Temperatures rose in early June with the melting of much of the snow. There was a slight drop in temperature in late June with a subsequent increase in July which had the highest mean monthly temperature. The highest temperature of the summer (22°C) was recorded in July. Below-freezing temperatures were recorded on 11 days throughout the summer.

Fig. 4. Daily maximum and minimum temperatures at 15 cms above the ground at Marmot Basin, May-August 1977.

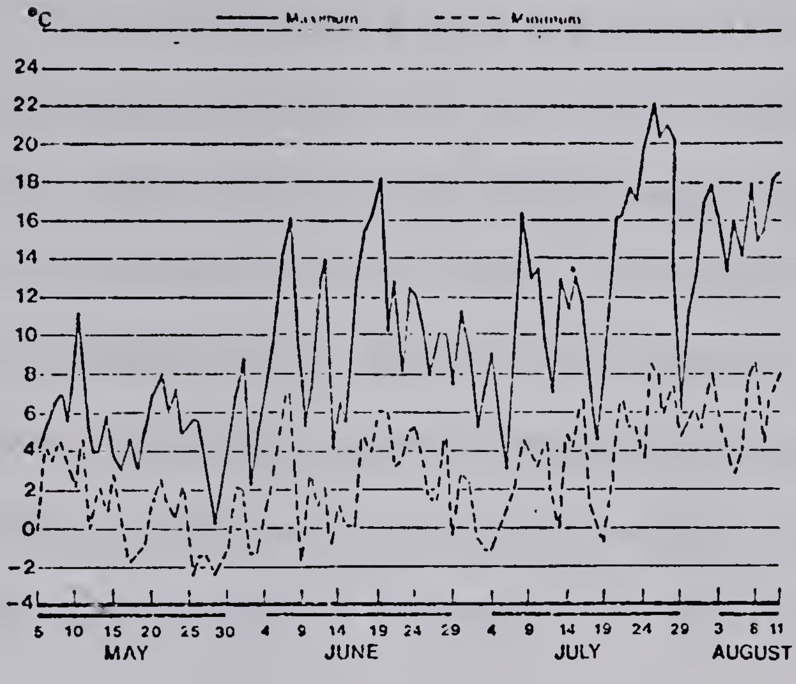


Fig. 5. Daily vapour pressure deficits at 15 cm above the ground at Marmot Basin, May-August 1977.

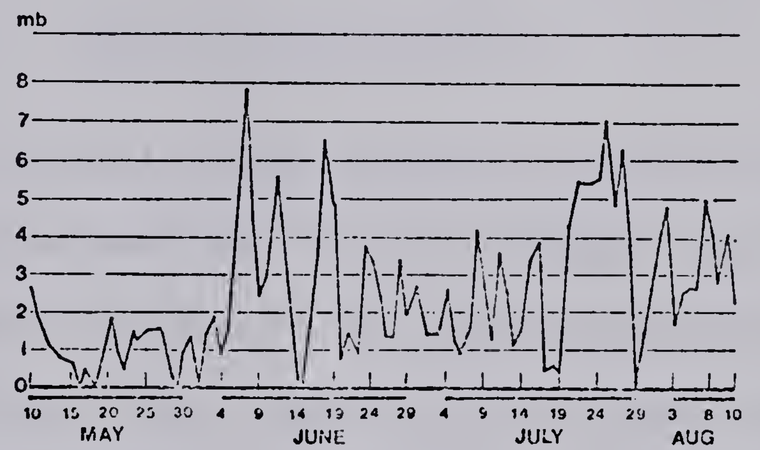


Fig. 6. Average weekly precipitation at 50 cm above the ground at Marmot Basin, May-August 1977.

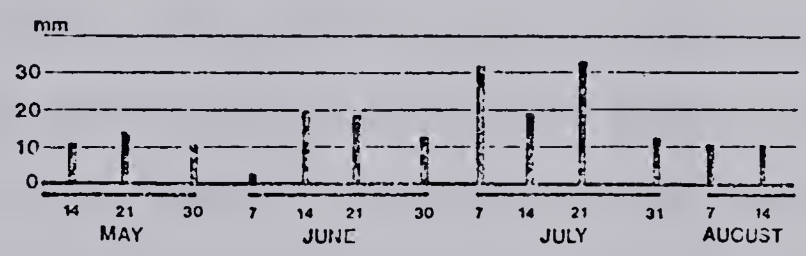
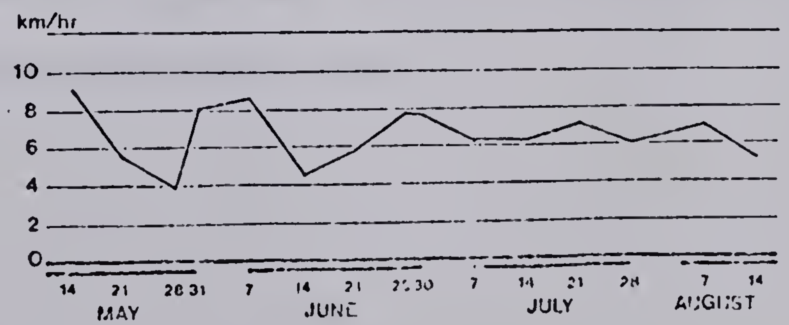


Fig. 7. Average weekly windspeeds at 1m above the ground at Marmot Basin, May-August 1977.



Precipitation

Precipitation in May averaged 10 mm per week, with most falling as snow (Fig. 6). There was scattered rain and snowfall in June, but most of the precipitation occurred in July when average weekly rainfall was 17-31 mm. The early part of August was fairly dry with more precipitation falling later in the month. Periods of heavy precipitation were rare and most of the rain and snowfall was light and scattered. Cloudy conditions occurred frequently throughout the summer of 1977. Strato-cumulus and cumulus formed the dominant cloud cover; numerous occurrences of fog were also reported.

Vapour Pressure Deficit

Vapour pressure deficits (VPDs) closely follow the trends of temperature and relative humidity (Fig. 5). Values ranged from 0 to 7.8 mbs, being highest in June and July, when temperatures were high and relative humidity was low. High VPDs (7.8 mb) were recorded early in June when air temperatures dropped below freezing and the soil was probably still frozen. This condition could potentially cause desiccation injury to some of the exposed alpine plants. Low VPDs (0-2.6 mb) occurred in May when air temperatures were low and melting snow maintained a high relative humidity. Low values were found throughout the summer during periods of precipitation or fog when relative humidity was approximately 100%.

Wind

Winds in Marmot Basin were primarily from the SE (Janz and Storr 1977). Windspeeds averaged 4-9 km/hr throughout the summer. Weekly windspeeds were most variable in May and June, maintaining a more steady speed of 6-7 km/hr in July and August (Fig. 7).

SOILS

The soils of Marmot Basin have developed primarily from sedimentary and metamorphic rock of the Wynd Formation (Leeson 1976a). This formation includes siltstones, mudstones, sandstones, quartzites and slates. These materials have been eroded by frost activity and transported by colluvial and fluvial activity (Leeson 1976a). A thin veneer of silty loess, which probably includes ash, overlies the weathered Wynd Formation materials. Pedogenesis is slower in the colluvium than it is in the loess (pers. comm. R. Wells). Soil profiles in many sites are altered by cryoturbation, solifluction, soil creep and avalanching.

The alpine soils of the study area can be classified as Regosolics, Brunisolics, Podzolics and Gleysolics (Canada Soil Survey Committee 1978). Regosolics underlie the unstable scree slope Shrub Tundra communities, Rock Tundra communities on patterned ground in exposed sites, and the sparsely vegetated, late-melting Snowbed Tundra communities. Brunisolics with thicker, better developed soil profiles are found beneath the lusher Heath, Meadow and some Rock Tundra communities. Well drained substrates have been reported for alpine

Brunisolics, but the cool temperatures and moist conditions found in these sites allow for the accumulation of organic materials and subsequent Brunisolic development (Bliss 1963). Wells *et al.* (1976) found Podzolic soils in the better drained Heath Tundra communities in Marmot Basin. Although podzolization occurs in some of the Brunisolics sampled in this study, none of the sampled soils were classified as Podzolics. Gleysolics occur in areas where soils are fine textured, have a high moisture retention capacity, are poorly drained, and therefore subject to periodic saturation and gleying.

REGOSOLICS

Orthic Regosols consisting of an Ah layer overlying undifferentiated parent materials are found beneath some of the more poorly vegetated Rock, Shrub and Meadow Tundra communities (Plate 2). The severity of the environment in these xeric, exposed sites results in limited organic matter production and in slow and limited soil development.

The soils beneath the sparsely vegetated *Salix nivalis-Vaccinium vitis-idaea* dominated Shrub Tundra found on exposed ridges were fairly coarse-textured and well-drained (Table 3). The coarse fraction content of the Ah horizon was greater than 50%. The organic matter and clay contents were low resulting in low cation exchange capacity. However, the levels of available N and K were comparable to those in the other soils in the basin. Soil pH ranged from 4.8 to 5.2, which was somewhat higher than Heath Tundra communities.

Plate 2. An Orthic Regosol. This profile was found beneath the *Salix arctica* - *Dryas octopetala* Shrub Meadows on an unstable N-facing scree slope. August 2, 1977.

Plate 3. A Gleyed Orthic Regosol. This soil was found in frequently saturated, late snow released sites The overlying vegetation is dominated by *Carex nigricans* (stand 17). August 2, 1977.

Table 3. The physical and chemical properties of soils in selected plant communities in Marmot Basin.

Group	Community type	Stand	Soil type	Horizon	Depth (cm)	Colour (dry)	Percentage composition >2mm coarse	<2mm sand	<2mm silt	<2mm clay	Texture Class	pH	Available nutrients in <2 mm fraction (ppm) N*	P	K	Na	S	Al	Mn	Exchangeable cations (meq/100g) Ca	Mg	Na	K	T.E.C.	Conductivity (mmhos)	Organic matter
ROCK TUNDRA	*Dryas octopetala-Cassiope tetragona*	1	O.DYB	Ah	0-2	10YR 3/2	47	74	2	23	SCL	5.2	0.5	4.5	92	11	32	0	0.0	8.2	0.8	1.5	0.3	22.8	0.1	M
				Bm	2-9	10YR 5/3	41	82	3	15	SL	5.3	0.5	1.0	21	13	2.0	14	1.8	2.0	0.04	0.7	0.2	23.1	0.1	L
				BC	9-11	10YR 5/3	25	66	8	25	SCL	5.0														
				C	11+	10YR 6/4	60	71	6	23	SCL	5.0														
SHRUB TUNDRA	*Salix nivalis-Vaccinium vitis-idaea*	38	O.R	Ah	0-2	10YR 3/2	65	79	4	18	SL	4.8	0.5	7.0	82	15	3.8	12	25	5.5	1.7	1.5	0.2	16.9	0.1	L-
				Bm	2-4	10YR 7/4	35	74	9	18	SL	4.8	0.5	0.5	13	10	1.0	35	1.2	1.5	0.04	1.0	0.1	10.2	0.1	L-
				BC	4+	10YR 8/3	54	80	6	14	SL	5.2	0.5	3.5	3	5	1.0	17	0.8	1.3	0.0	1.0	0.08	2.5	0.1	L-
	Salix arctica-Dryas octopetala	39	O.R	Ah	0-3	10YR 3/2	47	86	3	11	LS	4.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Bm	3-10	10YR 6/3	65	64	12	24	SCL	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				C	10	10YR 7/2	64	79	4	16	SL	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HEATH TUNDRA	*Phyllodoce glanduliflora-Artemisia norvegica*	19	O.DYB	Ah	0-5	10YR 4/3	3	69	2	29	SCL	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Ae	5-7	-	4	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Bm	7-15	10YR 5/4	3	50	3	47	SC	5.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				C	15+	10YR 8/2	60	65	13	22	SCL	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Phyllodoce glanduliflora-Antennaria lanata	18	O.DYB	Ah	0-11	10YR 4/3	36	71	1	28	SCL	4.9	0.5	2.0	38	16	3.2	28	14	2.0	0.3	1.3	0.0	22.3	0.1	L
				Bm	11-17	10YR 6/3	28	69	5	26	SCL	5.0	0.5	2.0	8	15	1.0	5	1.4	1.5	0.3	0.6	0.0	18.7	0.1	L
				C	17+	10YR 7/4	51	64	12	25	SCL	5.3	0.5	0.5	3	11	1.0	33	1.2	2.0	0.04	0.8	0.03	10.4	0.1	L
	Cassiope mertensiana-Salix arctica	4	E.DYB	Ah	0-1	10YR 3/2	3	84	4	12	SL	4.9	0.5	7.0	130	13	7.3	-	-	9.2	1.8	0.6	0.8	35.2	0.2	M
				Ae	1-10	10YR 4/3	3	75	3	17	SL	4.6	0.5	4.0	51	11	4.4	28	6.2	3.5	0.8	0.9	0.02	26.3	0.1	L-
				Bfj	10-16	10YR 6/4	51	65	9	21	SCL	4.5	0.5	0.5	11	6	1.0	38	1.0	1.7	0.2	0.5	0.0	10.0	0.1	L-
				C	16+	10YR 7/3	57	65	13	23	SCL	5.0	0.5	2.5	19	9	1.0	31	22	1.3	0.2	1.0	0.0	5.0	0.1	L-
	Cassiope mertensiana-Vaccinium scoparium	5	E.DYB	Ah	0-4	10YR 3/2	-	-	-	-	-	4.6	0.5	4.0	65	12	4.9	23	61	2.2	0.6	1.0	0.0	16.5	0.1	L-
				Ae	4-11	10YR 5/3	-	-	-	-	-	4.6	0.5	1.0	17	8	2.0	46	3.2	1.5	0.0	0.5	0.08	16.3	0.1	L-
				Bm	11-30	10YR 5/4	53	76	5	19	SL	4.8	0.5	2.5	23	8	1.0	42	1.2	1.2	0.2	1.3	0.0	8.2	0.1	L-
				C	30+	10YR 6/4	36	73	7	20	SL															
	Cassiope mertensiana-Luzula wahlenbergii	26	GLE.DYB	Ah	0-1																					M
				Ae	1-11	10YR 7/2	15	89	3	9	LS	4.3	0.5	3.0	147	23	6.3	0	0.0	2.8	0.6	1.2	0.2	17.5	0.2	L
				Bmgj	11-15	10YR 5/3	3	73	4	23	SCL	4.6	0.5	2.0	15	15	0.0	27	0.6	1.5	0.2	0.9	0.0	22.9	0.1	
				C	15+	10YR 7/3	42	78	7	15	SL	4.9														
MEADOW TUNDRA	*Salix arctica-Carex spectabilis*	20	GLE.DYB.	Ah	0-3	10YR 6/3	1	73	9	18	SL	4.8	0.5	7.5	68	20	3.8	24	23	2.0	0.4	0.9	0.01	19.0	0.1	L
				Ae	3-15	10YR 5/3	1	67	7	26	SCL	4.8	0.5	5.5	16	15	2.6	29	2.8	1.8	0.04	0.8	0.05	15.2	0.1	L
				Bmgj	15-35	10YR 6/3	1	74	8	17	SL	5.0	0.5	5.0	7.0	15	3.8	22	0.8	1.5	0.0	1.0	0.1	15.6	0.1	L
				C	35+	10YR 6/3	46	83	8	10	LS	5.1	0.5	2.0	5.0	12	2.0	14	2.4	1.5	0.0	0.4	0.0	24.0	0.1	L
SNOWBED TUNDRA	*Carex nigricans-Senecio triangularis*	17	GL.R	Ah	0-3	10YR 7/2	1	63	7	30	SCL															
				Cg	3+	10YR 6/3	1	60	4	37	SC	5.2	0.5	13	16	13	1.0	7	52	1.5	0.0	1.1	0.1	9.8	0.1	L

Gleyed Regosols, which are poorly-developed soils consisting of a thin Ah and Cg horizon, are found beneath the *Carex nigricans* dominated snowbed communities (Table 3; Plate 3). The parent materials are aeolian deposits containing ashy layers, which have accumulated in the depressional areas as a result of erosion and redeposition. Periodic saturation of these poorly drained sandy clay textured soils results in gleization and the Cg horizon. The shortness of the growing season in conjunction with the low soil temperatures found in these water-saturated sites limits soil development. The pH of the Regosolic in the *Carex nigricans* community was 5.0 to 5.2, which is higher than most of the soils in the Basin (Table 2). Organic matter content and total exchange capacities were low; levels of available K and exchangeable nutrients were low, however, available P levels were fairly high.

BRUNISOLICS

Dystric Brunisols, which are fairly acidic soils with a thin Ah and a thick Bm horizon, are common in the alpine zone of Marmot Basin. These soils are found beneath most Rock, Heath and Meadow Tundra communities. The soils in the fairly dry Rock Tundra and *Phyllodoce glanduliflora* dominated communities were Orthic Dystric Brunisols with an Ah-Bm-C profile. In more mesic, well-drained sites, organic material is leached out of the Ah horizon resulting in the development of an Ae horizon. These soils, classified as Eluviated Dystric Brunisols, and having an Ah-Ae-Bm (Bjf) (BC)-C profile, are found in the better-drained *Cassiope mertensiana* communities. Gleyed

Eluviated Dystric Brunisols are found in concave, poorly-drained Forb Meadow and *C. mertensiana* dominated sites. These soils are saturated periodically during the growing season and have an Ah-Ae-Bmgj-BC-C profile.

Orthic Dystric Brunisols underlie *Dryas octopetala - Cassiope tetragona, P. glanduliflora* and some *C. mertensiana* dominated communities (Table 3; Plates 4 and 5). Soils in these sites have a thin Ah, overlying a thick Bm horizon. The accumulation of iron and organic matter imparts an orange colour to the well-developed Bm horizon. Ae horizons are found in some soils, but in most cases this layer is too thin to classify the soil as an Eluviated Dystric Brunisol.

The Orthic Dystric Brunisol found underlying the *Phyllodoce glanduliflora* communities are not as nutrient rich as those found in the *Dryas octopetala - Cassiope tetragona* dominated sites (Plate 5). Soils in the *P. glanduliflora* communities have a sandy clay texture and high coarse fraction content. Organic material content is low. Total P and K, exchangeable K, Mg and Ca, and TEC are in the low-to-intermediate range (Table 3).

The soils in the *Dryas octopetala - Cassiope tetragona* communities have a slightly coarser sandy clay loam texture. Organic matter content is high, total P and K are in the intermediate-to-high range, exchangeable Ca and Na are high, and TEC is moderate (Table 3).

Eluviated Dystric Brunisols are found beneath better-drained *Cassiope mertensiana* communities (Plate 6). In poorly-drained *C. mertensiana* dominated hollows the soils are Gleyed Eluviated Dystric Brunisols. These soils had a thick Ae horizon overlying a Bm or Bmj;

Plate 4. An Orthic Dystric Brunisol. This soil has developed in coarse textured materials found in the center of the central cirque basin. The overlying vegetation is dominated by *Cassiope mertensiana*. August 2, 1977.

Plate 5. A well developed Orthic Dystric Brunisol. This soil was found beneath a *Phyllodoce glanduliflora* community (no. 18) August 2, 1977.

Plate 6. An Eluviated Dystric Brunisol. This soil has developed below a fairly mesic and well drained *Cassiope mertensiana* - *Salix arctica* community (no. 5). August 2, 1977.

Plate 7. An Eluviated Dystric Brunisol found beneath a lushly vegetated *Salix arctica* - *Carex spectabilis* Meadow Tundra community. August 2, 1977.

both layers have developed from the aeolian deposits. The coarse fraction of these horizons is low; the fines have a loamy to sandy clay loam texture. Both clay and iron accumulate in the B horizon. In some of the sites the Fe content of the B meets the criteria for a Bfj. Wells (pers. comm. 1977) found soils under similar plant communities in which the pyrophosphate-extractable Al and Fe content of the B horizon is sufficient to meet the criteria for a Podzolic soil. The pH of the Eluviated Dystric Brunisol sampled was low, ranging from 4.3 to 4.9. These soils are nutrient rich; the organic matter content of the Ah is high, total K and P, exchangeable Ca, Mg and K and TEC are high (Table 3).

Soils found beneath the late melting Meadow Tundra and some *Cassiope mertensiana* Heath Tundra communities are classified as gleyed Eluviated Dystric Brunisols. Impeded drainage during parts of the season has resulted in gley formation in the Bmfj horizon. The thin Ah, thick Ae and Bmgj horizons have developed from fine-textured, aeolian materials. The coarse fraction of these layers is negligible; the fines are loamy sand to sandy clay loam. The clay content of the B horizon of the Heath Tundra community is higher than that found in the other layers, indicating that there has been appreciable illuviation. The pH of the Meadow Tundra soils is 4.8 to 5.1, higher than the Heath Tundra soils which have a pH of 4.3 and are amongst the most acidic soils in the basin. The soils in the Heath Tundra hollows have a high organic matter content. Total exchange capacity is in the intermediate range. The Meadow Tundra communities soils do not have as great a TEC and are not as nutrient rich as those found in the Heath Tundra. Organic matter

content and TEC are quite low, available K level is in the intermediate range and available P is high; exchangeable nutrient levels are low (Table 3) (Plate 7).

CHAPTER V. RESULTS: VEGETATION

The results of the Bray-Curtis and Reciprocal Averaging ordinations were used to classify the 37 stands sampled in Marmot Basin into plant communities (Tables 4 and 5; Fig. 8). The results of transect studies were used to evaluate the environmental factors important in determining the distribution of plant communities. These communities were then classified into 5 tundra groups according to similarities in terms of their habitat and physiognomy. The descriptions of these communities include information on the environmental factors important in controlling their distribution.

ORDINATIONS

RECIPROCAL AVERAGING ORDINATION

A reciprocal averaging ordination of the 56 most important species in the stands sampled at Marmot Basin was calculated (Table 4). This table shows the relative abundance of these species (in scaled deciles) in the 37 stands. The species and stands are arranged according to their position along a gradient. *Cassiope mertensiana* dominated communities are found in the upper left corner of the table.

Table 4. A species-stand table calculated using a reciprocal averaging ordination. The numerical values indicate the relative abundance of the species in scaled deciles in the stands.

Species	Stand number																																				
	21	14	17	5	13	23	36	12	10	11	34	26	25	35	30	33	29	20	4	31	37	6	18	16	15	27	9	22	7	28	39	19	24	32	8	38	1
Minuartia rubella	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Luetkea pectinata	+	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phyllodoce empetriformis	+	1	+	+	2	-	+	+	+	1	+	+	+	-	+	-	+	+	-	-	-	+	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
Lycopodium alpinum	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Claytonia lanceolata	+	+	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex nigricans	+	+	8	+	-	+	+	+	-	-	-	+	-	-	1	+	+	+	+	+	-	-	+	-	-	-	+	+	-	-	+	+	+	-	-	-	-
Cassiope mertensiana	8	6	+	2	4	9	6	7	7	6	5	5	4	-	+	-	+	+	2	-	2	+	+	-	+	-	-	-	+	+	-	-	-	-	-	-	-
Phleum alpinum	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Senecio triangularis	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Luzula wahlenbergii	+	+	+	+	+	+	+	-	+	+	+	1	+	+	+	-	+	+	+	+	-	+	+	+	-	-	-	-	+	-	-	-	+	-	-	-	-
Ranunculus eschscholtzii	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Juncus drummondii	-	+	+	-	+	-	+	-	-	-	+	-	-	+	+	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Veronica alpina	-	-	+	-	-	-	-	-	-	-	+	+	-	+	+	+	+	-	-	+	+	+	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-
Deschampsia atropurpurea	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	+	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Hieracium gracilis	-	-	-	-	-	-	+	-	-	-	+	-	-	-	+	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-
Vaccinium scoparium	+	+	-	1	+	+	-	1	1	+	-	+	+	-	+	-	1	+	+	-	-	+	+	-	+	+	+	+	+	+	-	+	-	-	-	-	-
Pedicularis bracteosa	-	-	-	-	+	-	-	-	-	+	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Valeriana sitchensis	-	-	+	-	-	-	-	-	-	-	-	-	-	-	1	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anemone occidentalis	-	-	-	-	+	+	+	-	-	+	-	+	-	-	+	-	+	+	-	-	-	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-
Carex spectabilis	+	+	-	+	1	+	+	+	+	+	+	-	-	-	+	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-
Antennaria lanata	+	+	-	+	+	+	+	+	+	+	1	+	2	-	+	+	+	1	+	1	+	+	1	+	+	+	+	+	+	-	-	+	+	-	-	-	+
Trisetum spicatum	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-
Trollius albiflorus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epilobium alpinum	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Polygonum viviparum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-
Poa epilis	-	-	+	+	-	+	+	-	+	-	+	+	-	+	+	-	+	+	+	+	-	-	-	+	+	-	+	+	-	+	-	-	-	-	-	-	-
Arnica cordifolia	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	+	+	-	-	-	+	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-
Erigeron peregrinus	-	+	-	+	+	-	+	+	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-	-	+	-	+	+	-	+	-	-	-	-	+	-	-
Sibbaldia procumbens	-	+	+	-	+	+	-	-	-	-	+	+	+	-	+	+	+	+	-	+	+	+	+	+	-	-	-	+	+	-	-	+	+	+	-	-	+
Castilleja occidentalis	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+	+	-	+	+	-	+	-	-	-	-	-	-	-	+	-	+	-	-	-	-
Salix arctica	+	+	+	+	+	-	-	+	1	1	+	1	+	-	+	+	1	1	1	-	+	+	1	+	+	+	2	+	+	+	1	+	1	+	+	-	+
Luzula spicata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+	+	+	-	-	+	-	+	-	+	+	-	+	-	-	-
Sedum stenopetala	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-
Potentilla nivea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Phyllodoce glanduliflora	+	-	+	+	-	1	+	+	-	-	+	+	-	-	-	-	-	+	+	+	2	+	3	+	5	4	+	5	+	1	-	1	-	-	-	-	-
Silene acaulis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Carex deflexa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Stellaria ruscifolia	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-
Artemisia norvegica	-	+	-	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	1	+	+	1	+	1	1	+	1	+	+	+	-	-
Solidago multiradiata	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+	+	+	-	-	-	+	+	-	-
Hierochloe alpina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-
Selaginella densa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	+	+	-	+
Poa arctica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	+	-	+	-	-	+	+	-	-	-	+	-	-
Festuca brachyphylla	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-	-	+	+	+	+	+	+	+	+	-	-	+	+	+	+	-	-
Poa alpina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-	-	-	-	+	-	-
Potentilla diversifolia	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	+	-	-	-	+	-	-	-	+	-	+	+	+	-	-	-
Arenaria sagensis	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	+	+	-	-	+	+	+	-	-	-	-
Agropyron latiglume	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-
Gentiana glauca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	+	+	-	-	-	-	+	-	-	+	-	+	+	+	-
Agrostis variabilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	+	-	-	+	-	+	-	-	-	+	-	-
Antennaria alpina	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	+	+	+	+	+	+	-	+	-	+	+	+	+
Salix nivalis	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	+	+	-	-	+	+	-	-	-	-	+	+	-	+	+	+	+	4	1	+	+	+
Campanula lasiocarpa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-
Dryas octopetala	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	+	+	+	+	+	+	-	2	3	+	2
Vaccinium vitis-idaea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	+
Cassiope tetragona	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	+	+	1

Table 5. A stand similarity matrix based on the Percentage Similarity index, using Prominence Values of the 56 most abundant vascular species.

GROUP		COMMUNITY TYPE		STAND NUMBER	STANO NUMBER																																				
					1	8	32	38	24	39	9	7	16	28	19	22	15	27	18	37	23	4	21	34	25	5	10	12	14	13	11	36	26	20	29	30	6	35	31	33	17
I. ROCK	1a	*Dryas octopetala*	- *Cassiope tetragona*	1																																					
TUNDRA	1b		- *Salix nivalis*	8	58																																				
	1b			32	58	66																																			
II. SHRUB	2a	*Salix nivalis*	- *Vaccinium vitis-idaea*	38	26	24	30																																		
TUNDRA	2b		- *Salix arctica*	24	7	19	38	12																																	
	3a	*Salix arctica*	- *Dryas octopetala*	39	12	21	23	21	30																																
	3b		- *Artemisia norvegica*	9	8	22	28	8	37	38																															
	4a	*Artemisia norvegica*	- *Salix arctica*	7	11	27	33	16	26	41	59																														
	4b		- *Carex spectabilis*	16	3	22	17	.8	17	24	44	60																													
	5	*Salix barrattiana*	- *Phyllodoce glanduliflora*	28	10	19	19	7	11	17	31	52	44																												
III. HEATH	6a	*Phyllodoce glanduliflora*	- *Artemisia norvegica*	19	14	31	42	23	36	27	47	62	54	62																											
TUNDRA	6b		- *Salix arctica*	22	8	15	16	9	13	22	18	32	27	35	38																										
	6c		- *Vaccinium scoparium*	15	1	9	9	.2	8	7	13	21	22	37	32	86																									
	6d		- *Antennaria lanata*	27	7	17	17	8	14	22	25	38	31	41	42	80	77																								
	6d			18	2	10	10	.2	22	27	32	34	30	33	38	65	65	77																							
	6e		- *Cassiope mertensiana*	37	2	21	12	.3	16	19	26	38	34	32	42	53	49	62	66																						
	7a	*Cassiope mertensiana*	- *Phyllodoce glanduliflora*	23	1	2	3	0	3	3	8	.1	14	16	16	15	14	18	22	41																					
	7b		- *Salix arctica*	4	2	17	19	.3	27	32	38	52	47	29	42	22	18	29	40	62	37																				
	7c		- *Antennaria lanata*	21	1	.3	.2	0	2	.1	6	9	5	2	3	4	3	6	10	31	84	36																			
	7c			34	2	9	9	.4	8	9	17	20	18	12	13	10	10	16	32	47	61	49	69																		
	7c			25	2	9	5	0	14	18	22	30	14	7	12	12	11	20	41	45	47	53	53	73																	
	7d		- *Vaccinium scoparium*	5	1	2	2	0	2	2	8	10	13	6	5	6	11	14	16	32	15	42	86	64	56																
	7d			10	1	7	6	0	18	19	23	18	14	8	13	12	12	16	26	35	67	50	76	60	60	84															
	7d			12	1	6	5	0	14	18	17	16	14	7	13	11	12	14	23	36	66	50	76	62	61	85	86														
	7e		- *Phyllodoce empetriformis*	14	1	2	2	0	3	2	7	10	9	3	6	4	4	7	11	34	62	42	72	68	55	71	69	72													
	7e			13	2	4	4	0	5	5	8	12	18	7	7	8	9	13	16	35	46	46	54	61	61	61	59	59	73												
	7e			11	1	8	6	0	18	20	26	20	22	9	13	12	10	18	30	41	63	46	69	68	65	74	82	79	81	59											
	7e			36	1	7	3	0	4	5	10	15	11	9	9	8	13	12	16	38	57	43	74	75	63	71	69	80	61	75											
	7f		- *Luzula wahlenbergii*	26	1	6	6	0	16	20	24	20	15	8	13	13	13	19	35	42	57	53	60	73	70	64	69	73	65	57	71	67									
IV. MEADOW	10	*Salix arctica*	- *Antennaria lanata*	20	2	13	11	0	25	27	41	28	31	22	24	16	18	26	45	27	14	37	9	31	39	16	27	26	14	16	32	17	42								
TUNDRA	9	*Vaccinium scoparium*	- *Salix arctica*	29	3	12	8	1	24	30	38	26	25	15	21	15	16	24	43	27	13	36	11	26	41	25	38	34	14	18	33	19	41	68							
	8	*Valeriana sitchensis*	- *Carex nigricans*	30	1	11	10	0	10	11	16	20	29	20	15	13	18	21	22	16	9	27	8	18	25	23	20	23	17	25	22	14	28	53	46						
	11	*Carex spectabilis*	- *Festuca brachyphylla*	6	3	10	19	.1	15	15	22	25	34	17	23	13	14	17	17	11	6	32	6	12	14	16	10	15	9	25	19	8	13	20	21	33					
	12	*Luzula wahlenbergii*	- *Trisetum spicatum*	35	0	.3	.3	.4	.3	0	.3	.3	4	2	0	.4	.5	0	2	.1	4	.4	3	6	5	.7	.1	.2	.1	.5	1	15	5	7	5	8	12				
V. SNOWBED	15	*Antennaria lanata*	- *Sibbaldia procumbens*	31	2	11	12	1	10	19	25	26	48	18	25	10	11	17	30	21	14	33	7	37	24	13	8	9	17	14	20	16	25	44	32	34	25	9			
TUNDRA	14	*Carex nigricans*	- *Sibbaldia procumbens*	33	4	8	7	2	13	24	17	23	32	19	24	13	3	13	13	14	3	17	4	8	12	5	8	11	16	8	9	5	18	28	25	27	13	0	36		
	13		- *Senecio triangularis*	17	1	.5	.7	.2	1	1	1	2	5	2	4	2	2	1	2	2	1	3	1	3	1	2	1	3	1	1	1	2	7	15	8	18	5	9	15	15	

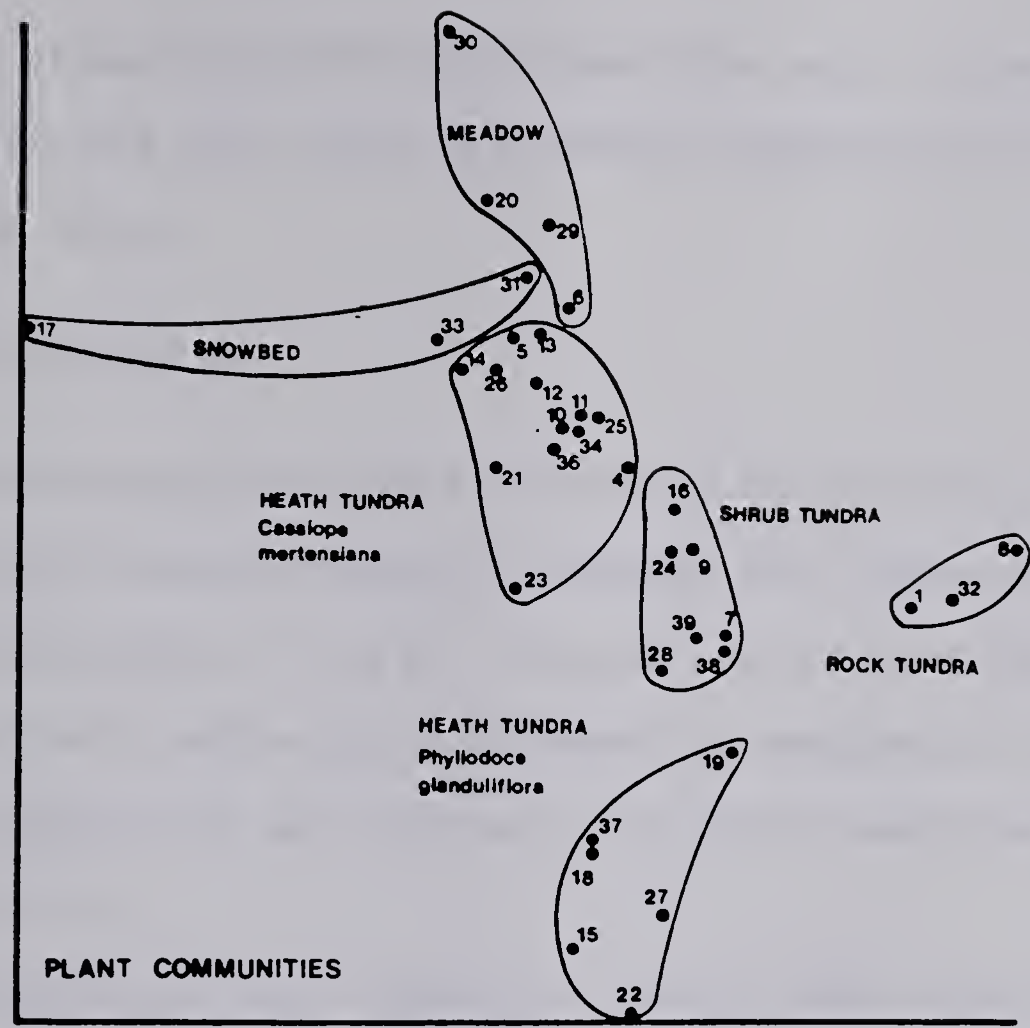


Fig. 8. Bray-Curtis ordination of Marmot Basin plant communities based on the Percentage Similarity index.

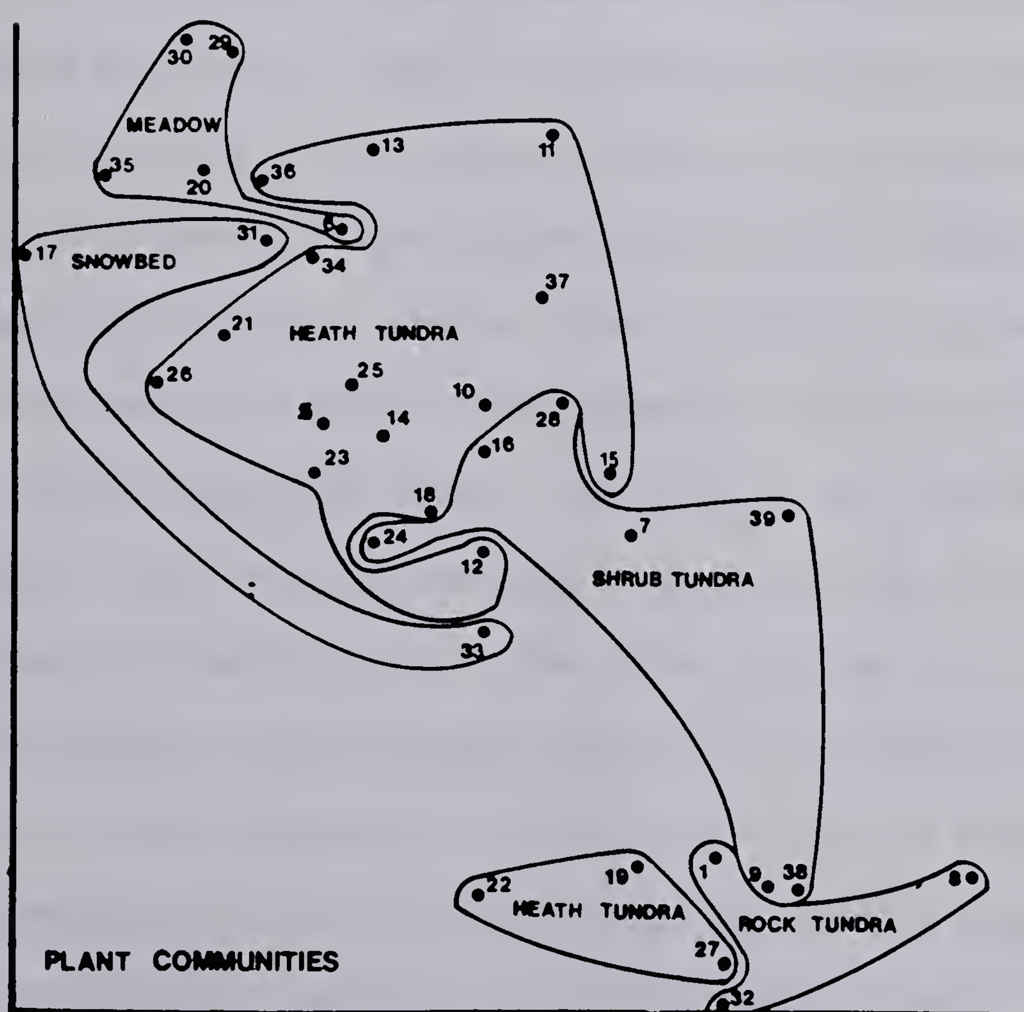


Fig. 9. Bray-Curtis ordination of Marmot Basin plant communities based on the Coefficient of Community similarity index.

Phyllodoce glanduliflora dominated communities occur in the center, and *Salix nivalis* and *Dryas octopetala* dominated communities occur in the lower right corner.

BRAY-CURTIS ORDINATION

Two-dimensional Bray-Curtis ordinations based on the percentage similarity (PS) and coefficient of community (CC) indices of similarity were calculated (Figs. 8 and 9). Selected environmental factors were plotted on the PS ordination to determine the importance of these factors in controlling the distribution of plant communities in Marmot Basin (Fig. 10).

The ordering of plant communities from the lower right corner to the upper left corner of the PS ordination is best correlated with the gradient of site moisture regime, from well-drained dry sites to poorly-drained wet sites. There is a gradient of snow release from the right to the left (Fig. 10). Both soil moisture and snow release date are determined in part by other factors such as site topography, slope, aspect and exposure. Convex sites on steeply sloping S-facing, exposed terrain melt out earlier and become dry faster than concave or flat, N-facing, protected areas. The type of soil found in an area also determines soil moisture content; coarse-textured soils are generally better drained and therefore drier than fine textured soils (Fig. 11). These factors appear to be the most important in determining the distribution of plant communities in the alpine zone of Marmot Basin.

The quantitative distributions of four key species were plotted on the PS ordination to determine the relationship between the previously described environmental factors and the abundance of these species

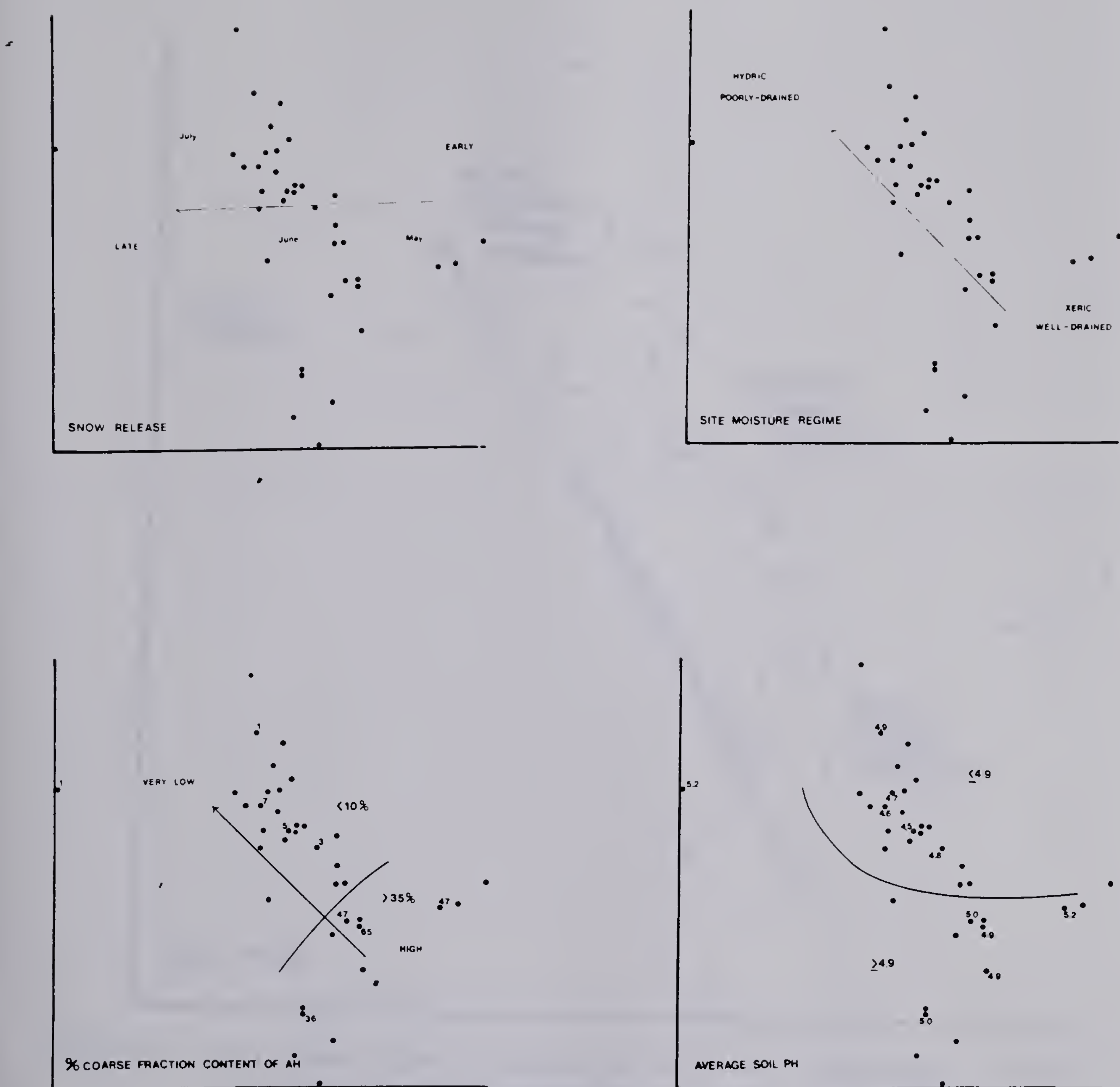


Fig. 10. Selected environmental gradients plotted on a Bray-Curtis Percentage Similarity ordination of Marmot Basin plant communities.

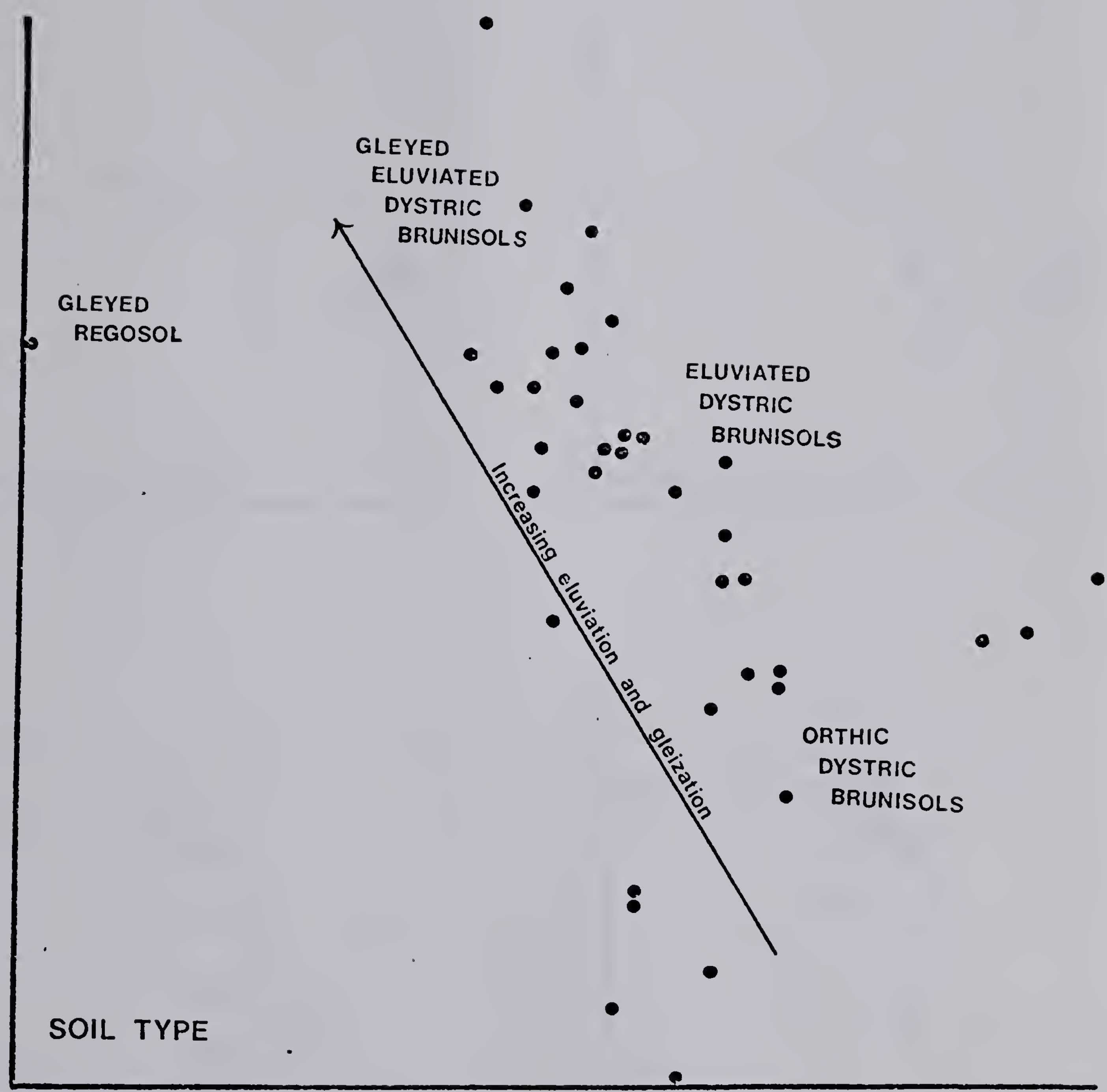


Fig. 11. Soil types found in Marmot Basin plant communities, plotted on the Bray-Curtis Percentage Similarity ordination.

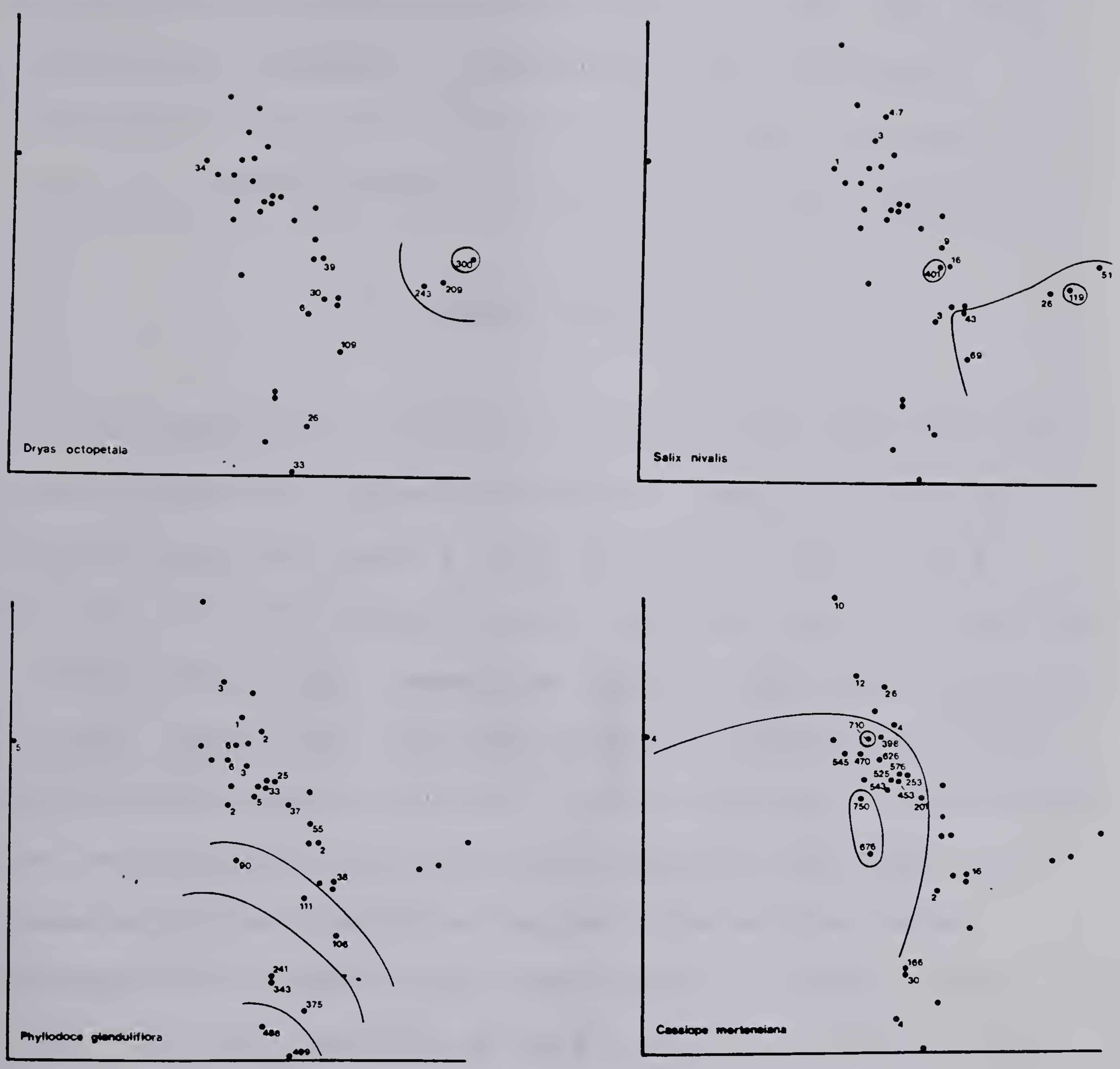


Fig. 12. Prominence Values of selected species on the Bray-Curtis Percentage Similarity ordination of Marmot Basin plant communities.

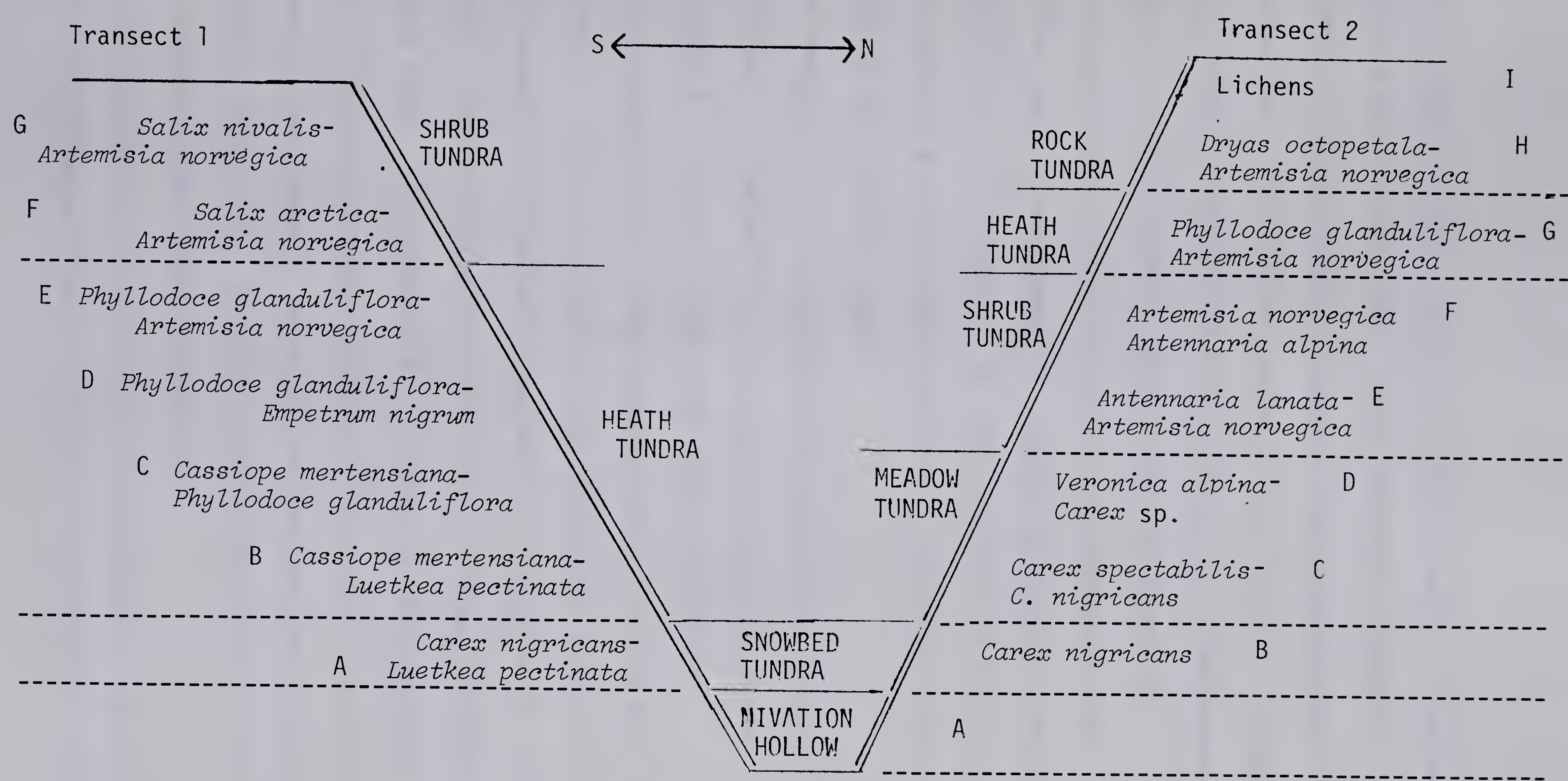
(Fig. 12). Lichens were found to be the most prominent in late-melting, well-drained snowbeds and in early snow-released, xeric Rock Tundra communities. *Dryas octopetala* is most abundant in early snow-released xeric sites, while *Salix nivalis* achieves greatest prominence in the moderately early snow-released, moderately moist sites. *Phyllodoce glanduliflora* is important in the moderately dry, well-drained sites that are snow-free fairly early in the summer. *Cassiope mertensiana* is most abundant in the later snow-released mesic sites.

TRANSECT STUDIES

Two transects that traversed the range of plant communities found along the sides of a snowbed were sampled. Transect 1 went up the N-facing slope and Transect 2 ran up the S-facing slope (Plate 8; Fig. 13). The distribution of species and plant communities along these transects reflects their response to a complex snow release and moisture gradient. Sites at the top of the transect are snowfree early in the spring and can become quite xeric; sites at the bottom of the transects are snow-released late and remain moist throughout the summer. The sequences of plant communities along both transects are similar, although certain communities are restricted to one transect or the other. The plant communities on the N-facing slope (Transect 1) are snowfree later than the communities found in a comparable slope position on the S-facing slope (Transect 2). The vegetation on the S-facing slope receives more solar radiation and, therefore, has warmer and drier soils than are found in comparable sites on the N-facing slope.

Plate 8. Two transects illustrating the distribution of plant communities along a snow release and moisture gradient. Transect 2 on the left was on a S-facing slope and Transect 1 on the right was on a N-facing slope. August 2, 1977.

Fig. 13. The distribution of plant communities along Transects 1 and 2.



TRANSECT 1

Transect 1 begins in *Carex nigricans* Snowbed Tundra at the base of the N-facing slope of the hollow. Other important species in transect segment A include *Luetkea pectinata, Luzula wahlenbergii* and *Cassiope mertensiana.* These three species are not found on Transect 2. *Antennaria lanata,* a ubiquitous herb, also occurs interspersed in the dense mat of *C. nigricans* that covers this site (Table 6).

Cassiope mertensiana, Luetkea pectinata and bryophytes are important in the Heath Tundra community (segment B) upslope from the Snowbed Tundra site. This community is restricted to the N-facing transect and occupies the same slope position as the Meadow Tundra community does on the S-facing slope.

Cassiope mertensiana is the overwhelming dominant in the next zone along Transect 1 (segment C). *Phyllodoce glanduliflora* and *Antennaria lanata* also occur in this Heath Tundra community.

Phyllodoce glanduliflora is the dominant species in the next two segments (D and E). *Empetrum nigrum* is the subdominant species in the Heath Tundra community represented by segment D. In segment E, found further upslope, *Artemisia norvegica* and *Cassiope tetragona* form the dominant ground cover. This community is similar to the *Phyllodoce glanduliflora - Artemisia norvegica* subtype of the Heath Tundra group.

Salix arctica and *Artemisia norvegica* are the dominant species in the next transect segment (F). Lichens are also important in this zone, which resembles Shrub Tundra communities.

Salix nivalis and *Artemisia norvegica* are prominent in the well-drained, early snow-released sites at the top of the transect. Lichens,

Table 6. The cover and number of vascular species in Transect 1 on the N-facing side of a snowbed.

TRANSECT SEGMENT	G	F	E	D	C		B	A		
QUADRAT NUMBER	1	2	3	4	5	6	7	8	9	10
Vascular species										
Festuca brachyphylla	1*	-	-	-	-	-	-	-	-	-
Dryas octopetala	1	1	-	-	-	-	-	-	-	-
Carex rupestris	2	-	1	-	-	-	-	-	-	-
Cassiope tetragona	1	-	2	-	-	-	-	-	-	-
Castilleja occidentalis	+	-	-	-	-	-	-	-	-	-
Artemisia norvegica	2	2	2	-	-	-	-	-	-	-
Salix nivalis	2	+	-	1	-	-	-	-	-	-
Luzula spicata	-	+	+	-	-	-	-	-	-	-
Minuartia sp.	-	1	-	-	-	-	-	-	-	-
Salix arctica	-	2	1	1	-	1	-	-	-	-
Sibbaldia procumbens	-	+	-	-	-	-	-	-	-	-
Antennaria lanata	1	1	1	1	1	1	-	1	1	1
Phyllodoce glanduliflora	-	-	2	3	1	1	1	-	-	-
Veronica alpina	-	-	1	-	+	1	-	-	+	-
Empetrum nigrum	-	-	-	2	-	-	-	-	1	-
Cassiope mertensiana	-	-	-	-	5	5	3	-	2	-
Luetkea pectinata	-	-	-	-	-	1	2	2	2	2
Carex nigricans	-	-	-	-	-	+	1	2	3	3
Luzula wahlenbergii	-	-	-	-	-	-	+	1	1	1
Juncus drummondii	-	-	-	-	-	-	-	+	-	-
Bare rock and soil	-	-	-	2	-	-	-	-	-	2
Lichens	3	3	3	2	1	1	1	2	1	1
Bryophytes	2	2	2	2	1	2	3	3	2	2
No. of Vascular Species	8	8	8	6	4	7	5	5	7	4

*The cover of vascular species is expressed in Braun-Blanquet cover values.

Dryas octopetala and *Cassiope tetragona* are also important in this exposed site (segment G). Although this community resembles both the Rock Tundra and the Shrub Tundra communities it is closer to the latter.

TRANSECT 2

Transect 2 begins in the center of a nivation hollow (segment A). The shortness of the growing season in this site precludes plant establishment (Fig. 13; Table 7; Plate 8).

Carex nigricans occurs in clumps with low cover in the next segment (B). Further upslope, where snowmelt is somewhat earlier, *C. nigricans* forms a continuous mat.

Several types of Meadow Tundra (segments C, D and E) occur upslope from the *C. nigricans* snowbeds. Seepage waters keep these meadows moist throughout the summer. *Carex spectabilis* and *C. nigricans* form a lush cover in segment C. *Antennaria lanata* is visually prominent in the next segment (D), along with *Sibbaldia procumbens* and *Artemisia norvegica.*

Artemisia norvegica and *Antennaria alpina* are the dominant species in the better-drained, earlier snow-released sites of segment E, found upslope from the Meadow Tundra zone. This community is similar to the Shrub Tundra found elsewhere in Marmot Basin.

Phyllodoce glanduliflora and *Artemisia norvegica* are the most important species in the next segment (G). *Phyllodoce glanduliflora* is restricted to this segment on Transect 2, whereas *Artemisia norvegica* occurs throughout the transect. *Dryas octopetala* and lichens are also present in this community, but achieve greater importance further upslope.

Table 7. The cover and number of vascular species in quadrats in Transect 2 on the S-facing side of a snowbed.

TRANSECT SEGMENT	I	H				G		F	E		D		C		B		A
QUADRAT NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Vascular species																	
Antennaria alpina	+*	1	+	-	1	+	-	2	1	-	-	-	-	-	-	-	-
Salix arctica	1	1	-	1	1	-	1	-	-	1	1	-	-	-	-	-	-
Dryas octopetala	-	2	3	4	2	2	-	2	-	-	-	-	-	-	-	-	-
Artemisia norvegica	-	2	2	-	2	2	2	2	2	2	-	-	+	-	-	-	-
Solidago multiradiata	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Sibbaldia procumbens	1	-	-	-	-	1	1	1	1	2	-	-	-	-	-	-	-
Phyllodoce glanduliflora	1	-	-	-	-	3	2	1	-	-	-	-	-	-	-	-	-
Festuca brachyphylla	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Campanula lasiocarpa	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stellaria crassifolia	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Veronica alpina	-	-	-	-	-	-	+	-	-	-	2	2	1	-	-	-	-
Trisetum spicatum	-	-	-	-	-	-	-	1	-	-	-	-	+	-	-	-	-
Antennaria lanata	-	-	-	-	-	-	-	-	1	2	-	+	-	-	-	-	-
Carex spectabilis	-	-	-	-	-	-	-	-	1	+	1	1	2	5	-	-	-
Selaginella densa	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Castilleja occidentalis	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Juncus drummondii	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Potentilla diversifolia	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
Epilobium alpinum	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Carex nigricans	-	-	-	-	-	-	-	-	-	-	1	2	4	2	5	5	-
Bare rock and soil	1	-	2	2	3	3	3	-	-	1	-	1	-	-	-	2	5
Lichens	5	4	2	2	2	1	2	1	3	2	-	-	-	-	-	-	-
Bryophytes	2	2	2	1	2	2	2	1	-	-	1	1	-	-	-	-	-
No. of Vascular Species	4	6	4	3	4	6	5	6	7	6	7	7	5	2	1	1	-

* The cover of vascular species is expressed in Braun-Blanquet cover values.

Dryas octopetala dominates the exposed, early snow-released, well-drained site at the top of the transect (segment H). *Artemisia norvegica* is the subdominant species in this community. Lichens and *Salix arctica* are also important in this Rock Tundra community.

Lichens form the dominant ground cover in the Rock Tundra community at the top of Transect 2 (segment I). *Antennaria alpina, Salix arctica, Sibbaldia procumbens* and *Phyllodoce glanduliflora* are also found in limited abundance in this zone.

COMMUNITY DESCRIPTIONS

The results of the Bray-Curtis and Reciprocal Averaging ordinations and transect studies were used to help classify the 37 stands sampled at Marmot Basin into five alpine tundra groups: (i) Rock Tundra, (ii) Shrub Tundra, (iii) Heath Tundra, (iv) Meadow Tundra, and (v) Snowbed Tundra. Rock Tundra occurs in dry, early snow-released sites; Shrub Tundra occurs in more protected, more moist, somewhat later-melting areas; Heath Tundra occurs on stable, mesic, upland slopes over much of the Basin; Snowbed Tundra is restricted to late-melting mesic sites. Meadow Tundra consists of two herb-dominated subgroups with different habitat affinities: the Forb Meadow Subgroup is found in well-watered areas; the Graminoid Meadow Subgroup occurs on unstable scree slopes and on disturbance sites of gentler slopes. Almost half of the alpine zone in Marmot Basin is very sparsely vegetated or unvegetated scree slope.

ROCK TUNDRA GROUP

Rock Tundra communities occur on ridge tops and other exposed convex surfaces including the tops of solifluction lobes. Since very little snow accumulates on these windswept sites plants may be exposed to the desiccating forces of the wind, as well as below-freezing temperatures throughout the winter. These sites melt out early in the spring and, once snowfree, dry out rapidly.

1. *Dryas octopetala* Community Type (no. 1, 8, 32)

The Rock Tundra communities in Marmot Basin are dominated by *Dryas octopetala*, a semi-evergreen dwarf shrub, which reaches its greatest prominence in this type, forming mats with ca. 25% cover. Lichens are prominent, especially in the more exposed sites where they may cover more than 50% of the stand. Total plant cover ranged from 70-80%. Many vascular species found in these communities are cushion plants, e.g., *Antennaria alpina* and *Silene acaulis*. Dwarf shrubs including *Salix nivalis* and *Vaccinium vitis-idaea* are also prominent (Table 8).

Soil development in the Rock Tundra communities was minimal. The severity of the environment limits plant production and, therefore, organic material input: Most of the soils examined are Orthic Regosols which consist of a thin Ah horizon and a C horizon of unaltered parent material. In some more protected, more mesic sites, thicker and better-developed Orthic Dystric Brunisols are found. In all cases soils have a high coarse fraction content and are, therefore, well-drained. Large rocks are found scattered throughout most stands.

Table 8. Species structure of the Rock Tundra Group.

Community type and subtype	1a	1b	1b
Stand no.	1	32	8
Elevation (m)	2250	2436	2220
Slope	0^{o}	23^{o}	20^{o}
Aspect	E	E	S
Mean cover (%)			
Total plant	73	70	80
Vascular plant	42	55	56
Lichen	20	12	12
Bryophytes	11	3	12
Bare rock and soil	27	30	20
No. of vascular plant species	9	13	15
P.V. of vascular species:			
Dryas octopetala	243.1	206.3	309.0
Salix nivalis	26.5	119.4	53.2
Cassiope tetragona	97.2	-	0.3
Artemisia norvegica	-	50.3	5.4
Vaccinium vitis-idaea	2.7	-	43.3
Festuca brachyphylla	+	32.7	14.1
Antennaria alpina	0.5	0.6	27.8
Salix arctica	5.5	17.8	23.6
Gentiana glauca	-	2.3	0.8
Antennaria lanata	2.9	-	-
Sibbaldia procumbens	2.8	1.7	-
Silene acaulis	0.2	+	-
Arenaria sajensis	+	5.2	-
Potentilla diversifolia	+	1.3	-
Luzula spicata	-	1.0	+
Sedum stenopetala	-	0.8	-
Solidago multiradiata	-	2.5	1.0
Agrostis variabilis	-	-	14.2
Campanula lasiocarpa	-	+	5.1
Carex nigricans	-	-	4.1
Poa alpina	-	+	1.9
Hieracium gracile	-	+	-
Poa arctica	-	+	0.6
Trisetum spicatum	-	+	+
Poa pratensis	-	-	+
Arenaria rubella	-	-	+
Potentilla nivea	-	-	+
Empetrum nigrum	-	-	+
Polygonum viviparum	-	-	+
Potentilla ledebourania	-	-	+

Dryas octopetala communities can be divided into two subtypes: (a) *Dryas octopetala - Cassiope tetragona*; and (b) *Dryas octopetala - Salix nivalis*.

(a) *Dryas octopetala - Cassiope tetragona* Subtype (no. 1)

This subtype is best beveloped on the windswept N-facing sites near the tops of ridges. These sites were snow-covered for most of the winter, becoming snowfree early in May in 1977. Once exposed, the coarse-textured soils found in these convex sites dry out rapidly.

Cassiope tetragona, the second most common species, is virtually restricted to, and, therefore, highly characteristic of, this subtype. It is also the most visually prominent component, usually occurring in clumps interspersed amongst the lichens and *Dryas* mat. Other important species include *Salix nivalis, S. arctica* and *Vaccinium vitis-idaea*; the latter is indicative of this subtype, while the two *Salix* species are ubiquitous. Forbs are generally not important in this site. *Antennaria alpina, Sibbaldia procumbens* and *Silene acaulis,* all compact in growth-form, are the most frequently occuring forms. Graminoids are not very common; lichens and bryophytes have cover values of 20% and 15%, respectively. Total vascular plant cover is 42%, with bare rock and soil covering 27% of the ground surface.

(b) *Dryas octopetala - Salix nivalis* Subtype (nos. 8, 32)

This subtype was found near the top of exposed, well-drained S- and E-facing slopes that were snowfree early in May in 1977 (Plate 9). The plants in these sites have only a thin snow cover during the winter and, therefore, are exposed to the drying forces of the wind throughout the year. The dwarf shrubs, *Dryas octopetala* and *Salix nivalis,* and

Plate 9. A *Dryas octopetala - Salix nivalis* Rock Tundra community found on exposed, early melting, well drained ridges in the upper basin on Marmot Mountain (no. 32). This community grades into *Salix nivalis* dominated Shrub Tundra in later melting areas. July 29, 1977.

lichens form the dominant ground cover. *Cassiope tetragona,* a chionophile (Hrapko 1970), is rare in these earlier melting sites. *Artemisia norvegica* and *Festuca brachyphylla* occur interspersed with *Vaccinium vitis-idaea, Antennaria alpina* and *Campanula lasiocarpa.* Total vascular plant cover in the stands sampled was ca. 55%, which is about 15% greater than that found in the *Dryas octopetala - Cassiope tetragona* subtype. The total plant cover in both subtypes is comparable; lichens are slightly less prominent, having a cover of 12%. Bryophytes also have a somewhat lower average cover in this subtype. This subtype is more species-rich than the other Rock Tundra subtype, having 13-15 vascular plant species.

SHRUB TUNDRA GROUP

Plant communities dominated by deciduous shrubs, in which herbs may be the co-dominant components, are found in a variety of moderately early snow sites (Plates 10-14; Table 9). Most Shrub Tundra communities are found on steep-to-gently inclined terrain in sites that are fairly well drained. These sites usually receive some meltwater from nearby snowbeds during the summer. Some of the Shrub Tundra communities were found on S- or E-facing slopes that receive higher levels of solar radiation and, therefore, have warmer soil temperatures. The soils underlying these communities range from Regosolics in the more unstable or severe habitats, to Brunisolics in the more moderate sites.

Although relatively similar in habitat and floristic composition, the communities classified into this group differ markedly in physiognomy and species structure. The most prominent species include

Plate 10. A Shrub Tundra stand dominated by lichens. *Salix nivalis* and *Vaccinium vitis-idaea* are also important in this community (no. 38). August 8, 1977.

Plate 11. A *Salix nivalis* - *Salix arctica* Shrub Tundra community. This community was found in a moderately well drained, site in the upper basin, that has a fairly deep winter snow cover (no. 24). August 7, 1977).

Table 9. Species structure of the Shrub Tundra Group.

Community type and subtype	2a	2b	3a	3b	4a	4b	5
Stand no.	38	24	39	9	7	16	28
Elevation (m)	2250	2410	2295	2220	2220	2280	2175
Slope	0°	5°	20°	10°	15°	39°	5°
Aspect	0	NE	N	SE	E	E	E
Mean cover (%)							
Total plant	85	92	76	84	74	62	90
Vascular plant	15	72	32	54	74	53	85
Lichen	66	13	36	9	13	3	4
Bryophyte	11	7	12	29	3	6	1
Bare rock and soil	15	8	24	16	26	39	10
No. of vascular plant species	14	15	22	26	22	27	35
P.V. of vascular species							
Salix arctica	-	108.2	89.8	177.5	49.4	44.2	6.2
Artemisia norvegica	+	34.7	24.9	115.1	102.3	132.9	99.6
Antennaria lanata	1.0	9.6	-	42.3	30.0	23.7	-
Festuca brachyphylla	-	22.4	+	35.7	21.2	-	10.6
Dryas octopetala	34.0	-	30.6	4.0	24.6	-	111.5
Phyllodoce glanduliflora	-	-	-	1.7	38.7	55.6	4.7
Carex spectabilis	-	-	2.2	0.1	-	62.8	0.3
Antennaria lanata	1.3	+	-	1.5	3.8	20.0	-
Castilleja occidentalis	-	1.1	20.5	0.1	-	+	-
Luzula spicata	-	-	14.4	0.4	8.7	6.2	-
Trisetum spicatum	0.3	-	+	+	-	0.5	-
Campanula lasiocarpa	+	+	+	-	-	0.1	-
Vaccinium vitis-idaea	35.0	-	+	2.0	-	-	-
Gentiana glauca	1.0	-	-	-	0.5	-	-
Potentilla ledebouriana	+	-	-	-	-	-	-
Empetrum nigrum	+	-	-	-	-	-	-
Salix nivalis	43.0	401.6	0.2	15.0	7.0	-	2.7
Potentilla diversifolia	-	10.3	+	-	-	-	7.5
Arenaria obtusiloba	-	0.4	-	-	-	-	-
Ranunculus eschscholtzii	-	+	-	-	-	-	-
Poa arctica	-	-	8.9	0.9	-	-	0.6
Draba paysonii	-	-	3.0	-	-	-	-
Agrostis variabilis	-	-	2.3	-	0.5	0.1	-
Carex nigricans	-	0.4	2.2	0.2	-	-	+
Hieracium gracile	-	-	0.2	-	-	-	-
Saxifraga bronchialis	-	-	+	-	-	+	-
Hierochloe alpina	-	-	-	10.9	-	-	-
Erigeron peregrinus		-	-	0.8	-	-	+
Arenaria obtusiloba	-	0.4	-	0.8	0.5	-	+
Carex phaeocephala	-	-	+	0.2	-	-	-
Poa pratensis	-	-	-	+	-	-	-
Cassiope mertensiana	-	-	-	-	16.2	-	1.7
Solidago multiradiata	-	-	-	0.4	5.0	-	-
Poa alpina	-	-	-	0.9	5.4	3.2	-
Polygonum viviparum	+	-	-	-	0.7	-	0.5
Phyllodoce empetriformis	-	-	-	-	+	+	+
Sibbaldia procumbens	-	5.2	-	-	0.5	61.3	
Poa cusickii	-	-	-	0.9	-	8.9	-
Sedum stenopetala	-	-	-	-	-	8.1	-
Veronica alpina	-	0.4	+	-	-	6.7	+
Deschampsia atropurpurea	--	-	-	-	-	0.3	-
Saxifraga occidentalis	-	-	-	-	-	0.3	-
Epilobium alpinum	-	-	-	-	-	+	-
Saxifraga rhomboidea	-	-	-	-	-	+	-
Draba stenoloba	-	-	-	-	-	+	-
Phleum alpinum	-	-	-	-	-	+	
Salix barrattiana	-	-	-	-	-	-	248.0
Trollius albiflorus	-	-	-	-	-	-	38.9
Arnica cordifolia	-	-	-	-	-	5.0	23.4
Cassiope tetragona	0.8	-	-	-	-	-	17.0
Vaccinium scoparium	-	-	-	1.7	2.0	-	11.8
Stellaria crassifolia	-	-	+	-	-	-	5.5
Luzula wahlenbergii	-	0.6	-	-	0.5	-	3.9
Senecio triangularis	-	-	-	-	-	-	1.7
Anemone occidentalis	-	-	-	-	0.5	-	1.6
Agropyron latiglume	-	-	-	-	-	-	1.5
Pedicularis bracteosa	-	-	-	-	-	-	0.3
Gentianella propinqua	-	-	-	-	-	-	+
Arabis lyallii	-	-	-	-	-	-	+
Senecio pauciflorus	-	-	-	-	-	-	+
Petasites frigidus	-	-	-	-	-	-	+
Carex atrosquama	-	-	-	-	-	-	+
Carex stenochaeta	-	-	-	-	-	-	+

the shrubs, *Salix arctica, S. nivalis* and *S. barrattiana,* and *Artemisia norvegica,* a forb. These species are either dominant or subdominant components of most Shrub Tundra communities.

The Shrub Tundra Groups can be classified into the following communities: 1) *Salix nivalis,* 2) *Salix arctica,* 3) *Artemisia norvegica,* and 4) *Salix barrattiana.*

2. *Salix nivalis* Community Type (nos. 38, 24)

Two subtypes of the *Salix nivalis* community were found. Both occur in fairly exposed, well-drained, moderately late-melting sites that have coarse-textured soils. Dwarf shrubs, including *S. nivalis, S. arctica* and *Vaccinium vitis-idaea* are the most important vascular species.

(a) *Salix nivalis - Vaccinium vitis-idaea* Subtype (no. 38)

Plant communities dominated by lichens and bryophytes, in which *Salix nivalis* and *Vaccinium vitis-idaea* are the most prominent vascular species occur on top of Eagle Ridge (Plate 10). These sites have a moderately thick snow cover and are not snowfree until midsummer. Once exposed, the plants are subjected to the desiccating forces of the wind. Since there is no upslope source of water once the snowbanks in the vicinity melt, these sites can become quite xeric. Soils in this stand are very coarse-textured and poorly developed.

Total vascular plant cover was only 15%, lichen cover was 66%, bryophyte cover 10%, and bare rock and soil cover 16%. *Salix nivalis, Vaccinium vitis-idaea* and *Dryas octopetala* are the only vascular species with appreciable importance in this stand. Only 14 vascular

plant species were found in this community, one of the more species-poor communities in the study area.

(b) *Salix nivalis - Salix arctica* Subtype (no. 24)

Plant communities dominated by *Salix nivalis* were found on slightly elevated sites in the shallow upper basin (Plate 11). The snow cover is moderately deep and the *S. nivalis* communities here were frequently not snowfree until late June. Meltwaters from the surrounding snowbanks keep this site moist throughout the summer. The coarse texture of the soil, along with the elevated topography of these sites results in good drainage.

Salix nivalis, a tiny prostrate dwarf shrub, forms an almost continuous mat in this stand. *Salix arctica*, a more upright dwarf shrub, is the second most prominent species. *Artemisia norvegica*, *Festuca brachyphylla* and *Potentilla diversifolia* occur along with the willow species.

Lichens are quite prominent, covering *ca.* 13%. Although its total plant cover is close to 100%, this stand is relatively species-poor with only 15 vascular plant species recorded.

This subtype is quite distinctive in terms of species structure and shows less than 38% similarity to any other community. It is most similar to Rock Tundra communities that occur upslope from it in earlier snow-released sites in the upper basin at Marmot.

3. *Salix arctica* Community Type (nos. 39, 9)

Salix arctica dominated communities are found in protected, moderately early-melting, well-watered sites. These areas have a shallow snow cover, and are usually snowfree in June.

Two distinct subtypes were found: (a) *Salix arctica - Dryas octopetala*, and (b) *Salix arctica - Artemisia norvegica.*

(a) *Salix arctica - Dryas octopetala* Subtype (no. 39).

Plant communities dominated by *Salix arctica* are found near the top of the N-facing wall of the basin (Plate 12). Snow cover is moderately deep and melt occurred in June in 1977. Seepage waters from upslope provide moisture throughout the summer. This community occurs on a well-drained, stabilized scree slope; there is some evidence of rock striping in sections of the stand.

Salix arctica occurs in clumps along with *Dryas octopetala, Artemisia norvegica, Castilleja occidentalis* and *Luzula spicata.* Some important graminoids include *Carex nigricans, Poa arctica* and *Trisetum spicatum.* Lichens and bryophytes are both prominent. Lichen cover is 36% and bryophyte cover 12%. Total plant cover is *ca.* 75% (Table 9).

This stand has 22 vascular plant species, and is in the intermediate range in terms of species richness.

The *Salix arctica - Dryas octopetala* community shows the greatest similarity to other Shrub Tundra communities, especially the *Salix nivalis - Salix arctica* and the *Artemisia norvegica - Salix arctica* subtypes.

(b) *Salix arctica - Artemisia norvegica* Subtype (no. 9)

Plant communities dominated by *Salix arctica* and *Artemisia norvegica* are found on slightly raised terrain in more protected sites on SE-facing slopes at Marmot Basin. These sites have a moderately shallow snow cover and melt out early in the spring. Once snowfree, meltwaters from upslope keep these sites well-irrigated and fairly moist during the summer.

Plate 12. A *Salix arctica - Dryas octopetala* Shrub Tundra community found on well watered N-facing scree slopes (no. 39). August 7, 1977.

Other important species in this subtype include *Antennaria lanata*, a ubiquitous species, *Festuca brachyphylla* and *Salix nivalis*. Bryophytes are quite prominent and cover *ca.* 30% of the ground. Lichen cover is *ca.* 10%. *Phyllodoce glanduliflora* occurs in scattered patches throughout the stand. Total plant cover is *ca.* 85%; vascular plant cover is *ca.* 55%. A total of 26 vascular plant species were recorded in this community, making it relatively species-rich.

This subtype resembles both the other Shrub Tundra and the Meadow Tundra communities in terms of species structure.

4. *Artemisia norvegica* Community Type (nos. 7, 16)

Artemisia norvegica dominated communities are found in the more mesic, well-watered, early melting sites. These communities have a fairly lush plant cover. Shrubs, especially *Salix arctica*, form the dominant plant cover in these communities.

Herbs, including *Artemisia norvegica* and *Carex spectabilis*, are also prominent. Two subtypes were sampled: (a) *Artemisia norvegica* - *Salix arctica*, and (b) *Artemisia norvegica* - *Carex spectabilis*.

(a) *Artemisia norvegica* - *Salix arctica* Subtype (no. 7)

This subtype was found in an elevated site on a heavily skied part of slope A (Fig. 3). This subtype is snow-released somewhat earlier and dries out more readily than the *Artemisia norvegica* - *Carex spectabilis* subtype. *Artemisia norvegica* is the most prominent species in this community, with *Salix arctica* the subdominant species. *Festuca brachyphylla*, although lower in cover, is the most visually prominent vascular plant. *Dryas octopetala*, *Cassiope mertensiana* and *Phyllodoce glanduliflora* are present in the discontinuous shrub layer, but are

not prominent. *Antennaria lanata*, a ubiquitous herb in the study area, is also found in low abundance in this community.

Bare rock and soil cover more than 25% of the stand. Bryophyte cover is 13% and lichen cover 3%.

This stand has 22 vascular plant species, making it moderate in species richness compared with other communities in the study area.

(b) *Artemisia norvegica - Carex spectabilis* Subtype (no. 16)

Lushly vegetated, rock stripe communities dominated by *Artemisia norvegica* and *Carex spectabilis* occur on the steep E-facing scree slopes in the central basin (Plate 13). This area was snow free in May, 1977. Meltwaters from upslope irrigate these sites throughout the summer.

Sibbaldia procumbens, Phyllodoce glanduliflora and *Salix arctica* are prominent in this subtype. Within the vegetated stripes total plant cover is close to 100%, most of it attributable to vascular plants. Neither mosses nor lichens achieve high cover in this plant community. This stand is quite rich floristically; 33 vascular species were noted.

5. *Salix barrattiana - Phyllodoce glanduliflora* Community Type (no. 28)

Salix barrattiana is the overwhelming dominant species in the distinctive communities found along the sides of small streams at Marmot Basin (Plate 14). These sites are snowfree early in the spring and receive a continuous water supply throughout the summer. *Salix barrattiana* forms an almost complete layer, approximately 40 cm in height, over the streams. *Phyllodoce glanduliflora,* the second most

Plate 13. A lushly vegetated *Artemisia norvegica* - *Carex spectabilis* community developed on steep E-facing scree slopes no. 16. This community recieves meltwaters from upslope snowbanks throughout most of the summer. July 23, 1977.

Plate 14. A moderately tall Shrub Tundra community dominated by *Salix barrattiana* and *Phyllodoce glanduliflora* (no. 28). This community is found along streams in the lower alpine at Marmot Basin. July 23, 1977.

abundant species, forms a patchy layer beneath the *Salix*. Other understory herb species include *Artemisia norvegica, Arnica cordifolia* and *Trollius albiflorus,* the latter being characteristic of these communities. The composition of the lower layer varies considerably depending on the moisture regime of the microsites along the stream channels. Total plant cover in this multistratal community is 90%. Bryophytes are of negligible importance, lichens cover *ca.* 5% of the stand. This stand has 35 vascular plant species, more than any other at Marmot.

This community is most similar to the *Artemisia norvegica* dominated Shrub Tundra communities which also occur in well-watered sites.

HEATH TUNDRA GROUP

Heath dominated communities form the dominant plant cover throughout most of the well-vegetated part of the alpine zone of Marmot, i.e. excluding the scree slopes. Two distinct types of communities occur, one dominated by *Cassiope mertensiana* in the mesic, late-melting more protected sites, and another dominated by *Phyllodoce glanduliflora* in the more exposed, better-drained sites. In both communities the heath species are the overwhelming dominants.

6. *Phyllodoce glanduliflora* Community Type

(nos. 19, 22, 15, 18, 27, 37)

Plant communities dominated by *Phyllodoce glanduliflora* are found on convex sites which are snow covered early in the fall and snowfree fairly early in the spring (late May and early June in 1977). Once

exposed, the soils in these communities, which occur predominantly on steeply sloping E and SE-facing terrain, drain readily. Most sites receive meltwaters from upslope and, therefore, remain fairly moist throughout the summer (Table 10; Plate 15).

Phyllodoce glanduliflora is the most important species in this community, and often is twice as prominent as the second most common species. *Salix arctica, Vaccinium scoparium, Artemisia norvegica, Antennaria lanata* and *Cassiope mertensiana,* commonly occurring species in this study area, are the most frequent subdominants. *Poa cusickii, Carex spectabilis* and *Festuca brachyphylla* are the most important graminoids. Total plant cover ranges from 74-100%; lichens and bryophytes each cover from 2-25% of the stands sampled. Vascular species richness is low; most stands have 15-21 species.

The soils associated with this community are well-developed Orthic and Eluviated Dystric Brunisols.

This community is most similar to the Shrub Tundra communities in terms of species structure.

The *Phyllodoce glanduliflora* community can be divided into five subtypes on the basis of differences in the subdominant species. These subtypes also vary in terms of snow release dates and site moisture regime.

(a) *Phyllodoce glanduliflora - Artemisia norvegica* Subtype (no. 19)

Plant communities dominated by *Phyllodoce glanduliflora* in which *Artemisia norvegica* is the second most important species are found in elevated, well-drained but late-melting places in the center of the central cirque basin. This site was snowfree in mid-June 1977 and received meltwater seepage from the nearby snow bank early in the

Table 10. Species structure of the *Phyllodoce glanduliflora* Community Type, Heath Tundra Group.

Subtype	6a	6b	6c	6d	6e	6e
Stand no.	19	22	15	18	27	37
Elevation (m)	2205	2220	2280	2220	2190	2220
Slope	0	34°	36°	0	18°	10°
Aspect	0	E	SE	0	SE	N
Mean cover (%)						
Total plant	97	84	75	98	98	99
Vascular plant	54	78	74	82	68	73
Lichen	25	2	4	20	23	20
Bryophytes	14	4	6	13	4	10
Bare rock and soil	3	16	25	2	2	1
No. of vascular plant species	21	19	21	17	16	18
P.V. of vascular species:						
Phyllodoce glanduliflora	106.5	499.0	488.0	343.0	372.0	241.0
Cassiope mertensiana	-	-	4.7	30.0	49.4	186.5
Antennaria lanata	12.3	18.2	8.0	137.0	30.4	63.4
Salix arctica	43.1	37.2	1.7	100.0	37.3	46.4
Artemisia norvegica	90.0	28.4	33.0	38.0	43.3	42.0
Vaccinium scoparium	0.3	16.4	55.5	39.7	26.0	-
Dryas octopetala	-	36.0	-	-	6.3	-
Festuca brachyphylla	27.5	4.8	10.3	0.4	-	0.3
Sibbaldia procumbens	21.3	0.6	-	2.7	-	3.5
Carex spectabilis	5.9	-	5.0	5.6	4.4	5.5
Erigeron peregrinus	-	1.0	4.1	+	-	0.8
Antennaria alpina	2.2	1.3	0.8	-	0.8	-
Gentiana glauca	4.5	-	-	0.8	-	0.8
Carex nigricans/pyrenaica	4.5	1.0	-	1.7	-	-
Luzula spicata	0.3	-	-	2.5	-	0.3
Solidago multiradiata	-	1.3	-	-	0.8	-
Epilobium alpinum	-	0.5	-	-	-	-
Claytonia lanceolata	-	+	-	-	-	-
Senecio triangularis	-	+	-	-	-	-
Hieracium gracile	-	-	0.5	-	-	-
Poa epilis	-	9.7	13.3	-	-	0.4
Epilobium angustifolium	-	-	38.7	-	-	-
Phyllodoce empetriformis	-	-	1.7	-	-	-
Arnica diversifolia	-	-	0.4	-	-	-
Trisetum spicatum	-	-	+	-	-	-
Sedum stenopetalum	-	-	+	-	-	-
Danthonia intermedia	-	-	+	-	-	-
Carex deflexa	-	-	+	-	-	-
Luzula wahlenbergii	-	-	+	10.0	-	-
Poa pratensis	-	-	3.1	-	+	-
Salix nivalis	69.3	-	-	-	0.8	0.3
Agrostis variabilis	-	-	-	-	2.7	-
Potentilla diversifolia	0.7	-	-	-	1.0	-
Cassiope tetragona	7.4	-	-	-	-	-
Hierochloe alpinum	2.6	-	-	-	+	-
Campanula lasiocarpa	1.3	-	-	-	-	-
Stellaria crassifolia	0.3	-	-	-	-	-
Veronica alpina	-	+	-	-	-	0.5

Plate 15. A Heath Tundra community on a moderately exposed steep, E-facing slope. *Phyllodoce glandiflora* is the dominant species in this subtype (no. 18). July 26, 1977.

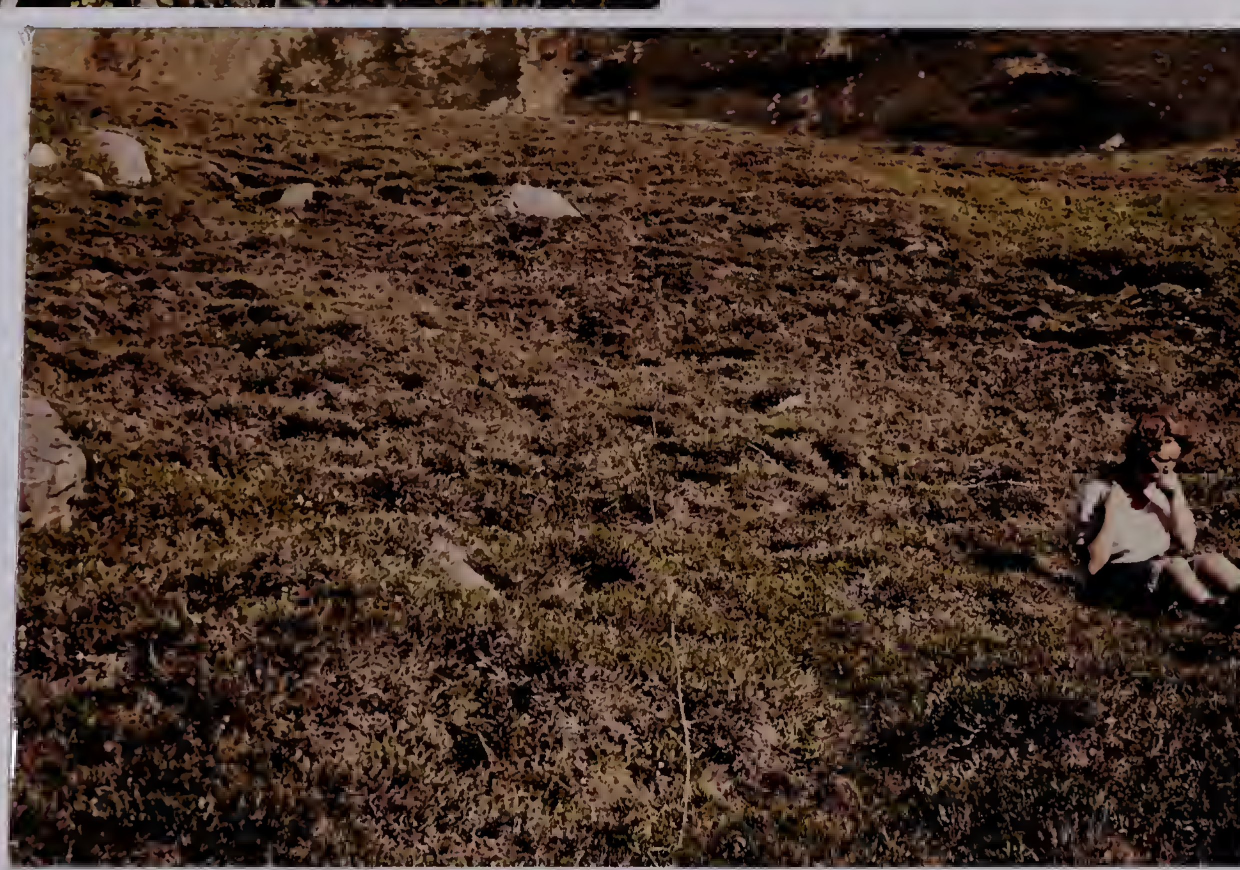


Plate 16. A *Cassiope mertensiana* Heath Tundra community found in a late melting, well watered and protected site (no. 21). July 26, 1977.

summer. *Salix nivalis* and *Salix arctica* were also important in this community. Lichens and bryophytes achieved greater prominence in this subtype than in any other *Phyllodoce glanduliflora* subtypes.

(b) *Phyllodoce glanduliflora - Salix arctica* Subtype (no. 22)

This subtype was found on a steep E-facing slope that was snowfree in June, 1977. *Dryas octopetala* is characteristic of this subtype. *Artemisia norvegica* and *Antennaria lanata* are also important. Total plant cover is somewhat greater than in the previously described subtype.

(c) *Phyllodoce glanduliflora - Vaccinium scoparium* Subtype (no. 15)

This subtype was found on steep well-drained SE-facing slopes that were snowfree early in May in 1977. It is characterized by the presence of *Epilobium angustifolium*. *Artemisia norvegica* is also quite prominent in this subtype. Bare rock and soil cover *ca*. 25% of the stand.

(d) *Phyllodoce glanduliflora - Antennaria lanata* Subtype (no. 18)

Antennaria lanata is the subdominant species in the later-melting *Phyllodoce glanduliflora* dominated communities. This subtype occurs on gently sloping and flat, mesic sites that were snow-released in June in 1977. Total plant cover is close to 100%; average lichen cover is *ca*. 20%.

(e) *Phyllodoce glanduliflora - Cassiope mertensiana* Subtype (no. 27, 37)

Cassiope mertensiana is the subdominant species in the stands found on mesic NE-facing sites that were snowfree late in June in

1977 (Plate 15). This later-melting site would tend to remain cooler than other sites with a more southerly exposure.

7. *Cassiope mertensiana* Community Type
(nos. 23, 4, 21, 34, 25, 5, 10, 12, 14, 13, 11, 36, 26)

Plant communities dominated by *Cassiope mertensiana* are found from treeline to 2340 m on gentle to steeply sloping SE, E, and NE-facing terrain. This community is best developed in protected, shallow depressions which have a deep snow cover in the winter and did not melt out until June in 1977 (Plate 16). Once snowfree, these sites continue to receive moisture from upslope. These hollows are found between solifluction lobes, in draws between ridges on steeper slopes, and on flatter terrain. More than half of the alpine vegetation on stable slopes in Marmot Basin is dominated by *Cassiope mertensiana.*

Cassiope mertensiana is the overwhelming dominant in this type, usually having a prominence value 2-4 times greater than that of the second most important species. The snowmelt date and soil moisture regime of a site determine in part which of the following species is subdominant: *Salix arctica, Phyllodoce glanduliflora, Antennaria lanata, Vaccinium scoparium, Phyllodoce empetriformis,* or *Luzula wahlenbergii.* These species are all quite common in the study area. Other widely occurring mesophytic species found in this community include *Artemisia morvegica, Erigeron peregrinus* and *Sibbaldia procumbens.* Species restricted to this community include *Claytonia lanceolata, Minuartia rubella* and *Luetkea pectinata.* Vascular species richness is low, ranging from 14-26 species per stand. Total plant

cover is close to 100%. Bryophyte and lichen cover varies between stands; in some sites where snowmelt is late, vascular plants other than *Cassiope mertensiana* are rare and bryophytes are subdominant.

Soils in the *Cassiope* dominated hollows are thick, well-developed Orthic, Eluviated and Gleyed Eluviated Dystric Brunisols, which have formed from acidic parent materials. Soils in these areas tend to remain moist during the summer.

This community type shows most similarity to both Meadow Tundra communities found in more mesic seepage sites and the other Heath Tundra communities found in more xeric sites.

This community type is divided into six subtypes which vary in the nature of the subdominant species, snow-release dates, and site moisture regime (Table 11).

(a) *Cassiope mertensiana* - *Phyllodoce glanduliflora* Subtype (no. 23)

Phyllodoce glanduliflora is important in steep exposed sites which were snowfree in June in 1977. These sites are somewhat later-melting and more mesic than those of the preceding Heath Tundra subtypes. This subtype is most similar to *Phyllodoce glanduliflora* communities.

(b) *Cassiope mertensiana* - *Salix arctica* Subtype (no. 4)

Cassiope mertensiana communities in which much of the *C. mertensiana* was dead and in which *Salix arctica* was the subdominant species were found in sites that were heavily skied. In addition to being susceptible to mechanical damage from skiers and machinery, the *C. mertensiana* plants in these areas were subjected to premature snow release. This resulted in damage and death of the *C. mertensiana* plants, which are

Table 11. Species structure of the *Cassiope mertensiana* Community Type, Heath Tundra Group

Subtype	7a	7b	7c			7d			7e				7f
Stand no.	23	4	21	34	25	5	10	12	14	13	11	36	26
Elevation (m)	2250	2202	2200	2325	2244	2190	2200	2200	2200	2244	2200	2190	2250
Slope	36°	15°	10°	26°	5°	30°	15°	0°	15°	15°	10°	25°	17°
Aspect	E	E	E	SE	E	E	S	0	SE	E	S	E	NE
Mean cover (%)													
Total plant	93	85	99	85	96	97	100	93	96	99	93	97	92
Vascular plant	93	85	99	85	96	97	100	93	96	99	93	97	92
Lichen	2	17	2	4	11	2	14	6	11	4	12	6	-
Bryophytes	7	15	13	5	3	7	9	13	9	16	7	7	1
Bare rock and soil	7	15	1	15	4	3		7	4	1	8	3	8
No. of vascular plant species	15	21	14	20	16	17	16	14	17	16	15	19	26
P.V. of vascular species													
Cassiope mertensiana	876.2	210.0	750.0	398.3	353.0	710.0	675.0	626.0	544.0	398.1	576.0	543.3	740.0
Phyllodoce glanduliflora	90.1	37.2	1.7	2.8		6.0	-	3.7	-	-	-		7.8
Phyllodoce empetriformis	-	-	8.8	13.4	27.0	12.6	56.5	1.9	121.0	210.0	112.0	47.0	1.4
Antennaria lanata	55.8	45.7	32.2	135.0	178.0	42.8	26.9	11.6	34.0	25.9	61.3	41.5	79.5
Vaccinium scoparium	.8	7.5	7.5	-	47.8	105.8	141.0	97.6	.6	36.0	27.2	-	64.0
Luzula wahlenbergii	31.0	.2	15.0	35.8	20.7	3.1	.4		.4	2.2	5.8	38.5	132.0
Salix arctica	-	94.4	1.4	9.3	74.0	6.2	108.0	81.5	1.0	13.2	113.0	21.2	97.2
Carex spectabilis	.8	50.4	.6	9.6	28.0	46.0	3.8	24.4	20.3	90.0	53.6	1.5	-
Artemisia norvegica	17.7	72.5	-	43.0	11.4	4.5	30.9	12.6	5.9	10.5	30.9		18.5
Carex nigricans	.8	13.4	.8	-	1.0	.4	-	15.5	51.3	-	-	3.8	45.0
Erigeron peregrinus	-	-	-	1.4	32.5	2.7	.4	.7	2.8	3.6	3.9	7.6	3.2
Poa epilis	4.9	1.2	-	9.4	-	.3	.4	-	-	-	-	5.5	1.5
Claytonia lanceolata	4.6	-	.3	.7	-	-	-	-	.4	-	-	0.4	-
Sibbaldia procumbens	.3	-	-	1.2	.1	-	-	-	4.2	2.2	-	-	1.6
Anemone occidentalis	.3	-	-	-	-	-	-	-	-	.6	-	2.9	0.3
Veronica alpina	-	-	-	2.2	-	-	-	-	.4	-	.4	-	3.9
Juncus drummondii	-	-	-	.3	-	-	-	-		-	-	0.8	-
Luetkea pectinata	18.2	-	12.7	-	-	-	-	-	-	-	-	-	-
Solidago multradiata	4.9	+	-	-	-	-	-	-	-	-	-	-	-
Festuca brachyphylla	-	28.3	-	-	-	-	1.0	1.0	2.6	-	-	-	-
Agrostis variabilis	-	6.9	-	-	-	-	-	-	-	-	-	-	-
Arenaria obtusiloba	-	2.0	-	-	-	-	-	-	-	-	-	-	-
Dryas octopetala	-	.2	-	-	-	-	-	-	-	-	-	-	-
Deschampsia atropurpurea	-	1 2	-	-	-	-	-	-	-	-	-	-	-
Gentiana glauca	-	1.2	+	-	-	-	-	-	-	-	-	-	-
Polygonum viviparum	-	-	-	-	-	-	-	-	-	-	-	-	+
Poa arctica	-	-	-	-	-	-	-	-	-	-	-	-	0.1
Trisetum spicatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Salix nivalis	-	-	-	1.7	-	-	-	-	-	-	-	-	-
Hieracium gracile	-	-	-	7.1	-	-	-	-	-	-	-	-	+
Castilleja occidentalis	-	-	-	5.0	-	-	-	-	-	-	-	19.5	18.5
Stellaria crassifolia	-	-	-	-	-	-	-	.4	-	-	-	-	-
Epilobium alpinum	-	-	-	-	-	-	-	-	6.0	-	-	0.4	+
Pedicularis bracteosa	-	-	-	-	-	-	-	-	-	.4	.4	-	-
Trollius albiflorus	-	-	-	-	-	-	-	-	-	-	-	-	-
Arnica diversifolia/latifolia	-	-	-	-	-	-	-	-	-	-	-	+	+
Valeriana sitchensis	-	-	-	-	-	-	-	-	-	-	-	-	0.1
Phleum alpinum	-	-	-	-	-	-	-	-	-	-	-	28.5	132.0
Potentilla diversifolia	-	+	-	-	-	-	-	-	-	-	-	-	-
Ranunculus eschscholtzii	-	-	-	-	-	-	-	-	-	-	-	-	+
Senecio pauciflora	-	-	-	-	-	-	-	-	-	-	-	-	+

intolerant of these conditions. *Artemisia norvegica, Carex spectabilis, Antennaria lanata* and *Phyllodoce glanduliflora* are important in this subtype. Total plant cover is *ca.* 85% lichens, bryophytes and bare rock and soil all cover *ca.* 15% of the stand. This subtype is most similar to some of the *Salix arctica* dominated Shrub Tundra communities that are found in moderately early-melting sites.

(c) *Cassiope mertensiana - Antennaria lanata* Subtype (nos. 21, 34, 25)

This subtype was found in protected hollows that melted out in mid-June in 1977. *Antennaria lanata* and *Luzula wahlenbergii* are both common in this well-watered subtype.

(d) *Cassiope mertensiana - Vaccinium scoparium* Subtype (nos. 5, 10, 12)

Heath Tundra communities in which *Vaccinium scoparium* is subdominant are found at lower elevations in hollows on E- and S-facing slopes that were snowfree in mid-June, 1977. This subtype has subalpine forest affinities.

(e) *Cassiope mertensiana - Phyllodoce empetriformis* Subtype (nos. 14, 13, 11, 36)

Stands in which *Phyllodoce empetriformis* is the subdominant species are found in late-melting, well-irrigated hummocky hollows and gentle S- and E-facing slopes at about 2230 m elevation. These sites were snowfree in mid-June, 1977. *Carex spectabilis* and *Antennaria lanata* are prominent in these stands.

(f) *Cassiope mertensiana - Luzula wahlenbergii* Subtype (no. 26)

The graminoids *Luzula wahlenbergii* and *Phleum alpinum* are both important and visually prominent components of this species-rich subtype. The sampled stand was found near the top of a late-melting NE-facing slope.

MEADOW TUNDRA GROUP

Several Meadow Tundra community types occur in the alpine zone of Marmot Basin. They are divided into two physiognomically and environmentally distinct subgroups. Lush forb dominated communities occur in seepage sites which remain moist in the summer and belong to the Forb Meadow Subgroup. The Graminoid Meadow Subgroup is dominated by grasses and sedges and consists of very sparsely-vegetated natural communities on late-melting, well-watered, unstable scree slopes; and of revegetating disturbance communities on abandoned roads in the basin (Table 12).

Forb Meadow Subgroup

Lush forb dominated meadows occur on gently sloping terrain in areas which were snowfree late in June in 1977. Seepage waters from upslope maintain high soil moisture and nutrient levels during the summer. Forb meadows occur in small pockets at the base of solifluction lobes, along meltwater streams, and in seepage sites throughout Marmot Basin.

Forbs and graminoids form a dense canopy *ca.* 30 cm in height.

Table 12. Species structure of the Forb Meadow and Graminoid Meadow Subgroups, Meadow Group.

Community Type	8	9	10	11	12
Stand no.	30	29	20	6	35
Elevation	2160	2190	2190	2220	2250
Slope	5°	0°	0°	15°	15°
Aspect	NE	SE	0	E	E
Mean cover (%)					
Total plant	100.0	100.0	100.0	46.0	6.0
Vascular plant	100.0	100.0	100.0	40.0	6.0
Lichen	0.8	2.0	+	-	0.8
Bryophyte	3.1	21.1	8.3	7.6	0.3
Bare rock and soil	+	+	+	54.0	81.0
No. of vascular plant species	29	26	31	29	17
P.V. of vasular					
Salix arctica	18.2	113.6	138.3	13.7	-
Vaccinium scoparium	80.6	133.0	55.4	21.3	+
Valeriana sitchensis	121.8	25.6	68.5	1.7	+
Carex nigricans	115.0	14.3	13.4	+	-
Antennaria lanata	26.4	86.6	102.3	5.8	-
Carex spectabilis	76.9	10.2	12.6	64.5	+
Senecio triangularis	2.7	6.3	65.6	-	-
Arnica cordifolia	40.6	14.2	30.3	1.7	+
Anemone occidentalis	36.9	33.6	24.6	1.0	+
Artemisia norvegica	35.8	20.1	42.6	12.3	-
Sibbaldia procumbens	0.3	19.5	39.2	3.9	-
Luzula wahlenbergii	24.3	12.6	38.0	10.0	21.0
Cassiope mertensiana	10.6	26.2	12.2	4.7	-
Erigeron peregrinus	10.3	10.3	11.3	-	-
Veronica alpina	7.9	14.7	+	-	1.4
Castilleja occidentalis	0.5	10.3	0.4	-	-
Deschampsia atropurpurea	8.9	-	0.3	2.0	-
Juncus drummondii	2.7	+	4.3	8.2	0.3
Potentilla diversifolia	+	0.3	6.7	-	-
Phyllodoce empetriformis	1.7	1.7	1.6	0.3	-
Pedicularis bracteosa	2.5	2,5	-	-	-
Poa epilis	2.0	0.3	0.8	-	1.4
Polygonum viviparum	1.1	5.5	-	-	-
Viola glabella	0.8	-	-	-	-
Trollius albiflorus	-	31.0	-	-	-
Phleum alpinum	+	3.4	0.1	2.8	-
Phyllodoce glanduliflora	-	-	2.9	1.7	-
Epilobium alpinum	+	-	0.3	-	0.3
Claytonia lanceolata	+	-	0.3	-	-
Poa arctica	-	-	0.2	+	-
Agrostis variabilis	-	-	-	80.0	-
Carex phaeocephala	-	-	-	2.0	+
Solidago multiradiata	-	-	-	1.0	-
Cardamine umbellata	-	-	-	1.0	-
Luzula spicata	-	-	-	0.8	-
Trisetum spicatum	-	-	-	0.8	3.0
Carex festivella	-	-	-	+	-
Stellaria crassifolia	-	-	-	+	-
Epilobium angustifolium	-	-	-	-	1.0
Luetkea pectinata	-	-	-	-	0.5
Ranunculus eschscholtzii	-	-	-	-	0.3
Cardamine bellidifolia	-	-	-	-	+
Oxyria digyna	-	-	-	-	+
Silene acaulis	-	-	-	-	+

Although the herb growth form is collectively most prominent, several shrub species achieve higher individual P.V.s than the leading herb species. *Salix arctica* and *Vaccinium scoparium*, both widely distributed dwarf shrubs in the study area, are prominent in these herb meadows. *Valeriana sitchensis*, *Carex nigricans*, *Antennaria lanata* and *Carex spectabilis* are the most common herb species in these communities. Vascular plant cover is close to 100% in these sites. These communities are amongst the most species-rich in the study area, with 26-31 vascular plant species per stand.

Soils in these well-watered sites are sandy loam textured, Gleyed Eluviated Dystric Brunisols.

Three different Forb Meadow communities are recognized.

8. *Valeriana sitchensis - Carex nigricans*
Community Type (No. 30)

This forb dominated community was found in a hygric seepage site at the base of a NE-facing slope. *Carex spectabilis* and *Arnica cordifolia,* the most visually prominent components, form a canopy along with *Valeriana sitchensis* above the shorter species including *Carex nigricans, Vaccinium scoparium* and *Artemisia norvegica.* Total plant cover is 100%; neither lichens nor bryophytes are very important.

9. *Vaccinium scoparium - Salix arctica*
Community Type (no. 29)

Herb dominated communities in which the shrubs *Vaccinium scoparium* and *Salix arctica* have the highest individual species prominence values are found in moist hollows close to treeline (Plate 17). *Antennaria lanata,* a ubiquist, and *Trollius albiflorus, Valeriana sitchensis* and

Plate 17. A Forb Meadow Tundra community dominated by *Vaccinium scoparium* and *Salix arctica* (no. 29). Herbs are an important component of this well watered, protected community. Vehicle tracks shown in the center of this photo illustrate the susceptability of this type of vegetation to disturbance. July 26, 1977.

Anemone occidentalis, all seepage site indicators, are important in this type. Total plant cover was 100%; bryophyte cover was 20%.

10. *Salix arctica - Antennaria lanata*
Community Type (no. 20)

This stand, which is dominated by both shrubs and forbs, occurred beside a meltwater channel close to the centre of a late-melting snowbed found in the central cirque basin. *Valeriana sitchensis* and *Senecio triangularis* are also important in this well-watered site.

Graminoid Meadow Subgroup

11. *Carex spectabilis - Festuca brachyphylla*
Community Type (no. 6)

Plant communities consisting of scattered clumps of graminoids and a few shrub and forb species are found along gravelly roadsides, on abandoned roadways, and in other disturbed sites. (Plate 18). Tall graminoids including *Carex spectabilis, Festuca brachyphylla* and *Luzula wahlenbergii* are the most prominent species in this community. *Vaccinium scoparium* and *Salix arctica* are also found in these areas. Total plant cover in the stand sampled was 46%.

12. *Luzula wahlenbergii - Trisetum spicatum*
Community Type (no. 35)

Very sparsely vegetated, graminoid dominated communities are found on the unstable scree slopes that cover almost half of the alpine zone in Marmot Basin. Total plant cover in the community sampled was *ca.* 20%, although in some areas total plant cover was less that 1%. *Luzula wahlenbergii, Trisetum spicatum, Poa cusickii, Veronica alpina* and

Plate 18. A Graminoid Meadow Tundra community on an alpine disturbance site dominated by *Carex spectabilis* and *Festuca brachyphylla* (no. 6). This community is revegetating an abandoned road in a heavily skied section of Marmot Basin. August 3. 1977.

Epilobium alpinum occur in scattered, widely-spaced clumps. Neither lichens nor bryophytes are important in this unstable environment. Only 17 vascular species were recorded, making this one of the more floristically depauperate communities of the study area.

SNOWBED TUNDRA GROUP

Snowbed Tundra communities are found in depressions in which snow accumulates, often not melting until late July or August. At Marmot, snowbed communities are found in the bottom of the upper basin and in the middle of the central basin (Plate 1, p. 9). These sites remain moist and cool during the summer since they receive meltwaters from nearby snowbanks. Plants growing in these communities, therefore, are adapted for a short, often less than two-month growing season, and for cold soil temperatures.

Snowbed Tundra communities are dominated by graminoids and forbs. *Carex nigricans* is consistently present and usually forms the dominant plant cover in hygric sites. Both *Antennaria lanata* and *Sibbaldia procumbens* are important in other, somewhat earlier-melting snowbeds. In other late-melting, better-drained areas, lichens are more extensive than the vascular species (Table 13, Plate 19).

Soils in these areas are fine-textured Gleyed Regosols that have a thin Ah and a gleyed Cg horizon. Impeded drainage in these cold saturated soils results in gleization. Because of the cold soil temperatures and short growing season, there is limited organic matter production and subsequent input into the soils and, therefore, profile development is weak (Plate 3, p. 30).

Table 13. Species structure of the Snowbed Tundra Group.

Community Type	13	14	15
Stand no.	17	33	31
Elevation	2220	2340	2340
Slope	0	0	0
Aspect	0	0	0
Mean cover (%)			
Total plant	98	84	94
Vascular plant	94	22	59
Lichen	1	55	28
Bryophyte	3	14	16
Bare rock and soil	2	16	7
No. of vascular plant species	16	14	16
P.V. of vascular species			
Carex nigricans	760.0	66.5	43.7
Sibbaldia procumbens	13.7	44.2	85.2
Veronica alpina	23.7	1.8	1.7
Senecio triangularis	64.9	-	-
Phleum alpinum	22.1	-	-
Juncus drummondii	8.7	-	0.3
Phyllodoce glanduliflora	4.7	-	2.9
Cassiope mertensiana	4.7	-	-
Valeriana sitchensis	4.0	-	-
Deschampsia atropurpurea	1.3	-	-
Epilobium alpinum	0.4	-	-
Antennaria alpina	1.5	1.7	-
Potentilla diversifolia	0.3	+	+
Minuartia sagensis	-	0.3	-
Antennaria lanata	-	19.4	117.4
Salix arctica	2.7	31.0	108.2
Artemisia norvegica	-	0.4	63.9
Carex spectabilis	-	+	54.1
Castilleja occidentalis	-	8.8	33.5
Luzula spicata	-	4.3	30.3
Poa leptocoma & pratensis	5.0	-	13.0
Hieracium gracile	-	-	7.2
Salix nivalis	-	0.8	2.8
Campanula lasiocarpa	-	-	+

Plate 19. Three Snowbed Tundra communities. A well watered *Carex nigricans* community is found in the centre in the lower lying terrain. A community dominated by lichens in which *Carex nigricans* and *Sibbaldia procumbens* are the most important vascular species occurs in the coarser textured material to the right of the gold-coloured *Carex nigricans* community. *Antennaria lanata - Sibbaldia procumbens* communities, which have a grey-green cast, are found at the base of the slopes at the left of the photo. July 26, 1977.

Snowbed Tundra is divided into three community types.

13. *Carex nigricans - Senecio triangularis* Community Type (no. 17)

Lush snowbed communities dominated by *Carex nigricans* were found in the late-melting and well-watered sites in the shallow upper basin and in the small central basin at Marmot (Fig. 3, p.6). In 1977, these sites were not snow-free until July. The meltwater channels which cut through these hummocky areas kept the fine-textured soils well-irrigated throughout the summer season.

Carex nigricans, a widely occurring dwarf sedge, reached its maximum prominence in this community. It is the overwhelming dominant, having a cover value of *ca.* 75%, and forming a dense thick turf in this stand. *Senecio triangularis*, a species characteristic of moist, nutrient rich sites, is the second most important species. *Veronica alpina, Sibbaldia procumbens, Valeriana sitchensis, Phleum alpinum* and *Juncus drummondii* were also present, but with fairly low cover in this stand. Most of these species were more prominent in Meadow Tundra communities which were snowfree earlier. Dwarf shrub and heath species occur in limited abundance on the tops of the small hummocks. Neither lichens nor bryophytes were important in this community. Total vascular plant cover was *ca.* 90%; bare rock and soil cover 10% of the stand.

This community is quite distinctive, bearing little resemblance to other communities in the basin. Stands of the Forb Meadow subgroup are most similar in terms of species structure.

14. *Carex nigricans - Sibbaldia procumbens* Community Type (no. 33)

Plant communities dominated by lichens, in which *Carex nigricans* and *Sibbaldia procumbens* are the most prominent vascular species are found in slightly elevated, well-drained sites close to a very late-melting snowbank in the shallow upper basin. This community was not snowfree until the end of July in 1977. Lusher *Carex nigricans* snowbeds of the preceding type are found on the finer-textured soils in the adjacent lower lying areas (Plate 19).

Lichens cover close to 50% of the stand; bryophyte cover is *ca.* 14%, and total vascular plant cover is only 15%. *Carex nigricans, Sibbaldia procumbens, Salix arctica, Antennaria lanata, Castilleja occidentalis* and *Luzula spicata* are the only vascular species with appreciable prominence in this stand. Only 14 vascular species were recorded in this floristically depauperate community.

This community is quite distinct and does not show ≥ 40% similarity to any other communities in the study area. It is most similar to the next Snowbed Tundra community type and some of the Shrub and Meadow Tundra communities.

The soils in this late-melting site are poorly developed. There has been little breakdown of the coarse-textured parent material. These coarser soils are better drained than the silty clays that are found underlying the *Carex nigricans - Senecio triangularis* community.

15. *Antennaria lanata - Sibbaldia procumbens* Community Type (no. 31)

Antennaria lanata dominated snowbeds are found in concave sites at the base of slopes in the shallow upper basin at Marmot and at lower

elevations in late-melting mesic sites. This community was snowfree somewhat earlier than the other two snowbed communities, i.e. late in July, is better drained than the nearby *Carex nigricans - Senecio triangularis* snowbed and, therefore, experiences warmer soil temperatures. Communities dominated by *Dryas octopetala* and *Salix nivalis* are found in the more exposed sites further upslope from this type.

Lichens are important in this stand, forming *ca.* 30% of the ground cover. Bryophytes cover *ca.* 15% of the site. Total vascular plant cover is *ca.* 60%. *Antennaria lanata*, a widely occurring species in the study area, is the dominant and most visually prominent vascular component. *Sibbaldia procumbens, Carex nigricans, C. spectabilis,* and *Artemisia norvegica* are also present with moderate cover. This stand is fairly species-poor; only 16 vascular species were found. It is most similar to the Forb Meadow communities in terms of species structure.

VEGETATION MAP

The vegetation of the alpine zone of Marmot Basin was sampled and mapped (Fig. 14; see packet in rear cover). The map units include individual plant community Groups and Types, as well as mosaics of these syntaxa. Ground surveys, community sampling, aerial and oblique photographs were used in the construction of this map (Plate 20).

Key

Colour	Vegetation
white	unvegetated scree slopes
yellow	sparsely vegetated areas
light blue	moderate plant cover, roads
royal blue	fairly dense plant cover
green	dense plant cover
black	dense plant cover - forests

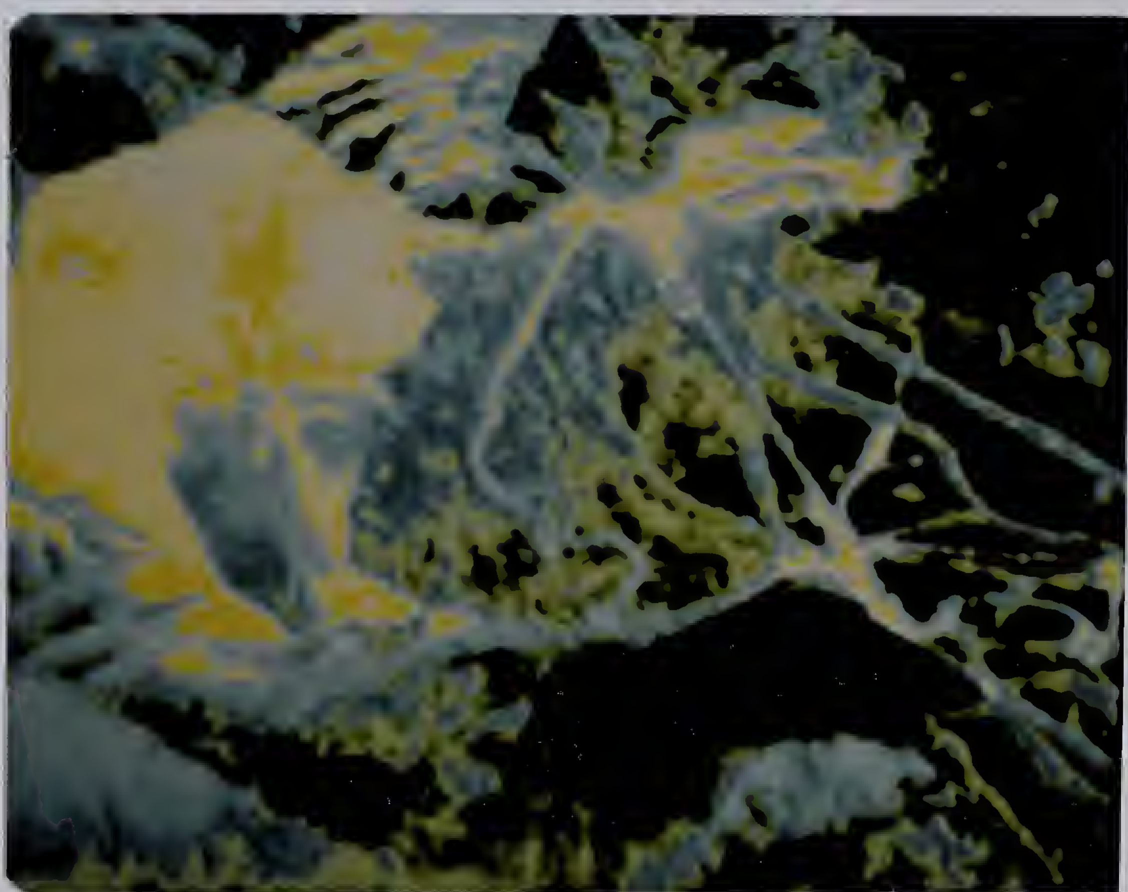


Plate 20. A density scanning photograph of the alpine zone of Marmot Basin (1972). Areas of similar colour are the same shade of gray on a black and white photograph. Yellow areas are the most sparsely vegetated and black areas have the most dense plant cover.

CHAPTER VI. DISCUSSION: VEGETATION

The vegetation of Marmot Basin has been previously classified by Wells *et al.* (1975) into two vegetation types or associations: 1) *Cassiope mertensiana* - *Phyllodoce glanduliflora* - *Artemisia norvegica* type, a dwarf shrub heath association found in subhygric lower alpine snow accumulation areas, and 2) *Cassiope tetragona* - *Dryas octopetala* - *Salix nivalis* type, an alpine tundra association found in mesic-subhygric alpine snow accumulation areas. Other vegetation types such as the *Caltha leptosepala* - *Valeriana sitchensis* association, a herb meadow type characteristic of hygric lower alpine snowmelt and seepage sites, have also been noted by Wells *et al.* (1975), in Marmot Basin.

A more detailed method of vegetation analysis was used in this study to classify the vegetation found at Marmot Basin into plant communities. "Stands," or areas of homogeneous plant cover which were dominated by the same species were classified as a plant community.

Heath Tundra communities dominated by *Cassiope mertensiana* and *Phyllodoce glanduliflora* form the dominant plant cover in the well-vegetated parts of the alpine zone of Marmot Basin. Rock Tundra and Shrub Tundra communities occur in the more xeric, earlier snow-

released sites; while Meadow Tundra and Snowbed Tundra communities are found in the later-melting, more moist sites.

The mesophytic Heath Tundra found at Marmot Basin resembles the vegetation found in high snowfall areas, e.g. the North Cascades, the Coastal Range and the Canadian Rocky Mountains west of the Continental Divide. The xerophytic Marmot Basin communities are more common in the drier parts of the Rocky Mountains, e.g. the Front Range and sections of the Main Range east of the Continental Divide.

ROCK TUNDRA

One type of Rock Tundra community, dominated by *Dryas octopetala*, was found on Marmot Basin. This community was not common, covering less than 5% of the alpine terrain. It is restricted to the earliest snow-released, most exposed xeric sites such as the tops of ridges or solifluction lobes. These areas have a shallow winter snow cover, since much of the snow in these unprotected sites is blown away (Hrapko 1970). Once snowfree, the soils in these areas dry up rapidly (Hrapko 1970). The plants in the Rock Tundra communities are often subjected to the desiccating and abrasive forces of the wind throughout the year. Coarse-textured, well-drained Regosolic soils in which very little soil development has occurred, are found in these sites. The slow rates of plant growth (Kuchar 1975) and limited moisture supply in these harsh environments (Hrapko 1970) limit organic matter incorporation and pedogenesis. Pockets of better developed Orthic Brunisols are found in the more protected Rock Tundra dominated areas in Marmot Basin.

Dryas octopetala communities similar to the ones found on Marmot are commonly found in other alpine regions of the Main Range, including Signal Mountain (Hrapko 1970, Hrapko and La Roi 1978), Sunshine (Knapik *et al.*1973), Bald Hills (Kuchar 1975), and Wilcox Pass (Crack 1977) in Alberta, and in Montana (Bamberg and Major 1968). A similar community dominated by *D. integrifolia* forms the dominant plant cover on Prospect Mountain in the Front Range (Mortimer 1978). *Dryas octopetala* communities are found in the Cascades (Douglas and Bliss 1977), but are not as widespread west of the Divide as they are in the Front Range and the Main Range of the Canadian Rocky Mountains.

The Rock Tundra communities at Marmot Basin are most similar to the *Salix nivalis* Shrub Tundra communities found in somewhat more protected, later-melting areas; and to the *Phyllodoce glanduliflora* - *Artemisia norvegica* Heath Tundra communities found on coarse-textured, well-drained soils in more protected habitats.

SHRUB TUNDRA

Shrub Tundra is the second most important vegetation type in the alpine of Marmot Basin, covering almost 20% of the landscape (Fig. 14). This group of plant communities is a highly diverse one, consisting of several distinct communities all occurring in moderately early snow-released, well-watered sites. Shrubs are the most prominent growth form in these communities. *Salix arctica, S. nivalis, S. barrattiana* and *Artemisia norvegica* are the dominant species in the communities classified as Shrub Tundra. Soils range from Regosolics in *Salix nivalis* communities, to well-developed Brunisolics

in *Salix arctica* and *Artemisia norvegica* communities, to Gleysolics in *Salix barrattiana* communities.

Shrub Tundra communities occupy a position intermediate between the more xeric, earlier snow-released Rock Tundra and the *Phyllodoce glanduliflora* Heath Tundra communities; and the later snow-released, wetter *Cassiope mertensiana* Heath Tundra, Meadow Tundra and Snowbed Tundra communities. Some of these Shrub Tundra communities dominated by *Salix arctica* and *Artemisia norvegica* are quite similar to Forb Meadow Tundra communities found on wet sites.

Plant communities similar to the Marmot Basin Shrub Tundra communities are commonly found elsewhere in the alpine zone of Alberta (Beder 1967, Kirby and Ogilvie 1969, Hrapko 1970, Trottier 1972, Knapik *et al.* 1973, Broad 1973, Wells *et al.* 1975, Ogilvie 1976, Mortimer 1978).

Salix nivalis dominated communities are the most common Shrub Tundra type at Marmot. The *Salix nivalis* - *Salix arctica* subtype occurs on coarse-textured soils in late-melting sites. In this subtype *Salix nivalis* is the overwhelming dominant, forming a mat over much of the stand. In the *Salix nivalis* - *Vaccinium vitis-idaea* subtype, found on exposed, somewhat earlier snow-released sites, lichens form the dominant ground cover.

Salix nivalis communities resembling the *Salis nivalis* - *Salix arctica* community found at Marmot Basin are common in the alpine region. *Salix nivalis* communities have been described from several alpine sites, including Snow Creek Valley (Beder 1967), Signal Mountain (Hrapko 1970), Sunshine (Knapik *et al.* 1973), Bow Summit (Broad 1973),

Wilcox Pass (Crack 1977) and Prospect Mountain (Mortimer 1978) in Alberta, and North Cascades (Douglas and Bliss 1977). Olgivie (1976) described a *Salix nivalis* dominated vegetation type commonly found in the alpine regions of the Rocky Mountains. *Salix nivalis* communities appear to be more common in the Rocky Mountains than in the higher snowfall areas.

These *Salix nivalis* communities are fairly similar to the *Salix nivalis - Salix arctica* community found at Marmot Basin. Although differing somewhat in species composition and structure, all are found in late snow-released sites on soils that remain moist throughout the summer (Trottier 1972). On Signal Mountain *Salix nivalis - Antennaria lanata* communities are found on fine-textured soils that have a high moisture retention capacity (Hrapko 1970). On Prospect Mountain, on more calcareous soils, *Salix nivalis* and *Salix arctica* are important in the snowbeds developed on Regosolic soils (Mortimer 1978). Ogilvie (1976) describes a *Salix nivalis - Salix arctica* community that occurs on N-facing avalanche slopes where snow cover is deep and soils are coarse colluvial Regosolics. In the higher rainfall North Cascades *Salix nivalis* communities are found on level-to-exposed steep S-facing slopes that are snowfree early in the spring (Douglas and Bliss 1977). The severity of the environment in these exposed late-melting sites, along with low soil temperatures resulting from meltwater saturation (Hrapko 1970), limits the rates of organic matter production and pedogenesis.

At Marmot Basin the *Salix nivalis* communities are replaced in earlier snow-released, more exposed sites by *Dryas octopetala* dominated

Rock Tundra communities, and in the later-melting, more mesic sites by Snowbed Tundra communities.

Shrub Tundra communities dominated by *Salix barrattiana* are also found in Marmot Basin. This community occurs at lower elevation in well-watered sites along the sides of streams. *Salix barrattiana* is overwhelmingly dominant, forming an almost continuous shrub layer.

This type of community is quite common in the Rocky Mountains and has been described from Snow Creek Valley (Beder 1967), Marmot Creek Basin (Kirby and Ogilvie 1969), Highwood Pass (Trottier 1972), Bow Summit (Broad 1974), Sunshine (Knapik *et al.* 1973) and Prospect Mountain (Mortimer 1978). Wells *et al.* (1975) also describe a *Salix barrattiana* community frequently found in Jasper.

These communities were found along streams and are well-irrigated during the summer. Snow remains in these sites until fairly late in the spring (Moss 1959). The soils in these sites ranged from Regosolics to Gleysolics, and were usually shallow and silty (Trottier 1972).

Although similar in habitat, there is some variability in the floristic composition of these communities. Wells *et al.* (1975) describe a *Salix barrattiana - Kalmia polifolia - Juncus drummondii* vegetation type typically found in the upper subalpine in hygric meadow sites in which there is occasional flooding. Beder (1967) and Broad (1973) describe a lower-elevation valley-bottom *Salix barrattiana - Salix vestita* community that occurs in moist sites that have a moderate snow cover. Ogilvie (1976) has described a *Salix barrattiana - Salix glauca* community that occurs along streams near timberline in

sites that have moderate snow cover. In Marmot Creek Basin *Betula glandulosa* is the subdominant species in communities found near watercourses (Kirby and Ogilvie 1969). On Prospect Mountain *Trollius albiflorus* is the subdominant species in the *Salix barrattiana* streambank communities (Mortimer 1978).

A different type of Shrub Tundra community, dominated by *Salix arctica* and *Artemisia norvegica*, is found at Marmot Basin in sites that are both snow-released sooner and more protected than the *Salix nivalis* dominated sites. These better-drained sites have warmer soil temperatures and are generally more favourable for plant growth and soil development.

Salix arctica communities similar to the ones found at Marmot Basin are common throughout the alpine zone of the Canadian Rockies. *Salix arctica* communities have been described from Signal Mountain (Hrapko 1970), Highwood Pass (Trottier 1972) and Prospect Mountain (Mortimer 1978) in Alberta. These communities are found in a range of mesic habitats. On Signal Mountain *Salix arctica - Arctagrostis arundinacea* communities are found in mesic sites on N-facing slopes, *Salix arctica - Antennaria lanata* communities occur on silty soils in high snow accumulation areas, and *Salix arctica - Dryas octopetala* communities are found on the tops of solifluction lobes (Hrapko 1970). Ogilvie (1976) described a *Salix arctica - Carex* community which occurs in sites that have a deep winter snow cover. Mortimer (1978) described a *Salix arctica - Salix nivalis* community found in late-melting snowbeds on Prospect Mountain.

Artemisia norvegica dominated communities are found in more mesic sites on Marmot Basin than those occupied by the *Salix arctica*

communities. *Artemisia norvegica* communities are apparently not very common in the Rocky Mountains, and have only been described from the Bald Hills (Kuchar 1975), where *Artemisia norvegica - Salix arctica* communities are found on early snow-released moist seepage sites on soils with a high clay content. *Artemisia norvegica - Luzula parviflora* communities occur in the Bald Hills in shallow basins that have a high water table. *Artemisia norvegica - Anemone occidentalis* communities occur on steep late snow-released sites that receive a steady moisture supply from upslope snowbanks, and *Artemisia norvegica - Antennaria lanata* communities are found in late-melting seepage sites in which there is negligible soil development. The *Artemisia norvegica - Carex spectabilis* community found at Marmot Basin occurs on scree slopes in sites that receive meltwater from upslope snowbeds, and is most similar to the *Artemisia norvegica - Antennaria lanata* communities found on the Bald Hills.

The *Salix arctica* and *Artemisia norvegica* communities are most similar in species structure to Meadow Tundra communities found in more favourable sites. Herbs are more prominent in the lush Forb Meadow Tundra, while dwarf shrubs are more important in the Shrub Tundra.

HEATH TUNDRA

Heath Tundra communities, dominated primarily by *Cassiope mertensiana*, and secondarily by *Phyllodoce glanduliflora*, form the principal plant cover in the alpine zone of Marmot Basin. *Cassiope mertensiana* communities are restricted to sites where winter snow cover is deep and, therefore, protects the underlying plants from fluctuating

spring temperatures (Bliss 1956). *Phyllodoce glanduliflora* communities occur in similar but drier and less protected sites.

Heath Tundra is commonly found in the high rainfall and snowfall regions of the Main Range of the Alberta Rockies and in the Coastal Mountains (Trottier 1972). *Cassiope mertensiana* forms "a characteristic community in B.C. and is found in the subalpine and alpine zones from southern Alaska and Yukon to central California, and east to Nevada and southern Montana" (Szczawinski 1962). *Cassiope mertensiana* communities are typically found in deglaciation cirques such as Marmot Basin (Archer 1964) and on N- and E-facing slopes (Broad 1973). These wind-protected, late-melting areas provide an ideal habitat for this species (Broad 1973).

General descriptions of *Cassiope mertensiana* dominated communities in Alberta have been made by Lewis (1919), Daubenmire (1943), Moss (1959), and Porsild (1959). Wells *et al.* (1975) also describe a *Cassiope mertensiana* vegetation type commonly found in Jasper. *Cassiope mertensiana* communities have been described from Signal Mountain (Hrapko 1970), Mount Edith Cavell (Kuchar 1972), Bow Summit (Broad 1973), Bald Hills (Kuchar 1975) and Prospect Mountain (Mortimer 1978). McLean (1970) found a similar community in the Similkameen Valley in interior B.C. *Cassiope mertensiana* communities are commonly found in the Subalpine Mountain Hemlock zone of the Coastal Mountains (Brooke *et al.* 1970). More detailed studies of this community in the Coastal Mountains have been done in Garibaldi Park (Brink 1959, 1964, Archer 1963) and in Bella Coola (McAvoy 1929, 1931). *Cassiope mertensiana* communities in the Cascade Mountains have been described by Franklin

et al. (1971), Douglas and Bliss (1977), and elsewhere in North America by Harshberger (1929).

Although all are dominated by *Cassiope mertensiana,* these communities differ somewhat in species composition and in habitat. In the higher snowfall more mesic Coastal Mountains, *Cassiope mertensiana* - *Phyllodoce glanduliflora* communities form the dominant cover in the alpine zone. In the Main Range of Alberta, *C. mertensiana* communities are found on N- and E-facing slopes in late snowmelt areas such as Marmot Basin. *Luetkea pectinata* is important in the *C. mertensiana* communities on the N-facing slopes of the alpine zone of the Bald Hills, Jasper (Kuchar 1975). On Prospect Mountain in the Front Range, *Cassiope mertensiana* - *Phyllodoce glanduliflora* communities are restricted to the late-melting snowbeds (Mortimer 1978).

Soils in these sites are usually well-developed Eluviated Dystric Brunisols or Gleyed Eluviated Dystric Brunisols, depending on the topography and drainage conditions. These soils are quite moist and remain cool during the summer. The mesic conditions found in these sites allow for the accumulation of organic material, which results in the relatively high nutrient content of these soils, and the fairly dense plant growth found in these communities (Douglas and Bliss 1977).

The *Cassiope mertensiana* communities that occur in the wetter sites resemble the Meadow Tundra communities, while those found in the more xeric sites resemble the *Phyllodoce glanduliflora* Heath Tundra and the *Salix arctica* Shrub Tundra communities.

Phyllodoce glanduliflora Heath Tundra communities are quite prominent in the alpine zone of Marmot Basin, but less extensive than the *Cassiope mertensiana* communities. *Phyllodoce glanduliflora* communities are

common throughout the alpine zone of Alberta and B.C.; within this area they are reported to be most common in the drier Interior Range and Front Range of Alberta (Trottier 1972). *Phyllodoce glanduliflora* communities have been described from sites in the Rocky Mountains including Snow Creek Valley (Beder 1967), Signal Mountain (Hrapko 1970), Highwood Pass (Trottier 1972), Bow Summit (Broad 1973), Sunshine (Knapik *et al.* 1973), Bald Hills (Kuchar 1975) and Prospect Mountain (Mortimer 1978). *Phyllodoce glanduliflora* communities have also been reported to occur on Garibaldi Mt. in the Coastal Mountains (Archer 1963) and in the North Cascades (Douglas and Bliss 1977).

In Marmot Basin *Phyllodoce glanduliflora* communities occur in sites that are somewhat more exposed, better drained and more xeric than are the sites where the *Cassiope mertensiana* communities occur. *Phyllodoce glanduliflora* communities are snow covered later and snow free earlier in the spring than are the *C. mertensiana* communities. In the North Cascades *P. glanduliflora* communities are found on the more exposed upper slopes (Douglas and Bliss 1977). Hrapko (1970) found these communities were most common on N- and E-facing slopes that have a deep snow cover. Ogilvie (1976) reports that *Phyllodoce glanduliflora* communities are common near tree islands on lee slopes that have a deep snow cover in the Rocky Mountains.

The soils of the *Phyllodoce glanduliflora* communities are generally better drained and, therefore, warmer than the soils of the *Cassiope mertensiana* communities. At Sunshine Mountain in Banff the *P. glanduliflora* communities occur on coarse-textured Dystric Brunisols which were derived from glacial till, while the *Cassiope mertensiana* communities occur on Eluviated Dystric Brunisols or on Gleyed Eluviated Dystric Brunisols.

The soils in these *Cassiope mertensiana* communities are finer textured, receive more seepage waters and are, therefore, more eluviated than the soils in the *P. glanduliflora* communities.

MEADOW TUNDRA

Five distinct community types dominated by herbaceous growth forms were found in well-watered sites in Marmot Basin. Three of these communities were very lush meadows in which forbs were more abundant than graminoids, although the species with the greatest individual prominence values were dwarf shrubs *(Salix arctica* and *Vaccinium scoparium)*; these three types comprise the Forb Meadow Subgroup. The fourth meadow type was a poorly vegetated successional plant community that was found in disturbed sites; the fifth community was very sparsely vegetated and occurred on unstable scree slopes; together they form the Graminoid Meadow Subgroup.

The lush Forb Meadow communities were found close to treeline in protected seepage sites in Marmot Basin. Meadows similar to these have been previously described from other alpine regions, and are common in the higher snowfall areas of the Cascades and the Coastal Range in B.C. and Washington (Archer 1964). Kuramoto and Bliss (1970) described a *Valeriana*- Forb Meadow found in the Olympic Mountains in Washington. Franklin *et al.* (1971) described a *Valeriana sitchensis* community which occurs in the North Cascades. Archer (1964) found a similar type of meadow in seepage sites on Garibaldi Mt. in B.C. Forb dominated meadows in which *Caltha leptosepala* and *Valeriana sitchensis* are the most prominent species, are typically found in hygric lower alpine snowmelt and seepage sites in Jasper National Park, Alberta (Wells *et al.*

1975). These meadow communities are similar to the *Valeriana sitchensis* - *Carex nigricans* community which occurs in similar habitats in Marmot Basin. Soils in these well-watered sites are thick turfy Eluviated Dystric Brunisols that have a relatively high nutrient content compared with other alpine soils. The lush growth of herbs in these sites allows for considerable organic matter production and therefore in well developed soils.

In somewhat less favourable sites (i.e. less protected and cooler) dwarf shrubs are the most prominent species in Forb Meadow Tundra communities. Two such community types were found at Marmot Basin: one was a *Salix arctica* - *Carex spectabilis* community and the other was a *Vaccinium scoparium* - *Salix arctica* community. Although dwarf shrubs have the highest individual species prominence values in these communities, herbs are the most prominent growth form. These dwarf shrub dominated communities are similar physiognomically to the *Salix arctica* and *Artemisia norvegica* dominated Shrub Tundra found at Marmot Basin, but are significantly different in terms of species composition. Forb Meadow Tundra communities are richer in mesophytic forbs and graminoïds than are the Shrub Tundra communities. Dwarf shrub dominated communities similar to those found at Marmot Basin have been reported from elsewhere in the alpine zone of Alberta. These communities have been discussed previously (see p. 93).

Two distinctly different Graminoid Meadow Tundra communities were found on Marmot Basin. The *Luzula wahlenbergii* - *Trisetum spicatum* community was found on sparsely vegetated scree slopes that cover almost half of the alpine zone. The somewhat better vegetated *Carex spectabilis* - *Agrostis variabilis* community was found on abandoned roads and other

disturbed sites. Both communities occur on gravelly sites that receive runoff from upslope. Although well irrigated, the coarse texture of the soils limits moisture retention in these two types, hence they are more xeric than the forb dominated types.

SNOWBED TUNDRA

Carex nigricans dominated communities are quite common in the alpine zone of the northern Rocky Mountains. In Marmot Basin *Carex nigricans* - *Senecio triangularis* communities are found in well-watered late snow-released sites. This is the most common Snowbed Tundra community type at Marmot, covering almost 10% of the alpine terrain. Similar communities have been described from Signal Mountain (Hrapko 1970), Sunshine (Knapik *et al.* 1973), Bald Hills (Kuchar 1975) and Wilcox Pass (Crack 1977), in Alberta, as well as in the North Cascades of Washington and B.C. (Douglas and Bliss 1977). *Carex nigricans* communities occur in sites that are not snowfree until July. In the summer, meltwaters saturate the fine-textured Regosolic soils that underlie these communities. The presence of fine ash and heavy clays in the soils results in a high moisture retention capacity, poor drainage and periodic saturation and gleization (Crack 1977, Douglas and Bliss 1977). The low temperatures found in these frequently water saturated soils, along with the shortness of the growing season found in these late snow-released sites, results in slow plant growth and soil development.

The *Carex nigricans* - *Sibbaldia procumbens* community is dominated by lichens and is found in very late-melting sites. Soils in these areas are coarse-textured and well-drained Regosolics. The severity

of the environment in this habitat greatly limits plant production and soil development. This community is not very prominent at Marmot Basin, covering less than 1% of the landscape. Although no previous descriptions of this community have been found, it is likely to be found in other sites, especially in high snowfall areas such as the Coastal Mountains.

The *Antennaria lanata - Sibbaldia procumbens* community is found in somewhat more favourable sites than either of the other two snowbed communities of Marmot Basin. It occurs in sites that are snow-released somewhat sooner and, therefore, have a longer growing season. The soil temperatures in these better-drained sites are warmer, allowing for greater plant growth and diversity. Communities similar to this one have been found elsewhere in the Coastal Mountains of B.C. (Archer 1964), in the North Cascades (Douglas and Bliss 1977), in the interior mountains of B.C. (Eady 1971), and on Signal Mountain in the Alberta Rockies (Hrapko 1970).

SUMMARY

In summary, the alpine vegetation of Marmot Basin is dominated by Heath Tundra communities. Rock Tundra and Shrub Tundra communities are found locally in the earlier snow-released, more xeric sites. Meadow Tundra and Snowbed Tundra communities occur in the later snow-released, wetter sites. Most of the plant communities of Marmot Basin also occur throughout the alpine zone of Alberta, British Columbia, and in parts of the northwestern United States. Heath Tundra communities are commonly found in snow accumulation areas throughout the Canadian Rocky Mountains and in the Coastal Mountains. Rock Tundra and Shrub Tundra communities are typically found in the more xeric, earlier

snow-released sites east of the Continental Divide. Meadow Tundra and Snowbed Tundra communities are more prevalent in the later snow-released sections of the Rocky Mountains west of the divide in the Coastal Mountains of B.C., and in the North Cascades and Olympic Mountains in Washington.

CHAPTER VII. RESULTS: IMPACT ASSESSMENT

IMPACT OF CONSTRUCTION

The construction of ski facilities in the alpine zone at Marmot Basin has led to several modifications in the natural environment, including:

1) the removal of vegetation and soil during the construction of access roads, buildings and ski lifts;
2) the subsequent erosion of exposed soil;
3) the disruption (by tracked vehicles) of the vegetation in the wet sites in the center of the basin;
4) the removal of krummholz during the construction of ski runs.

One main access road was built in the alpine to facilitate the construction of the Yellow T-bar and the Caribou Chair lifts. This road winds through the basin from the lower parking lot to the upper chalet and on to the top of Slope A (Plate 21, Fig. 3, p. 7). There are also several smaller side roads in this area.

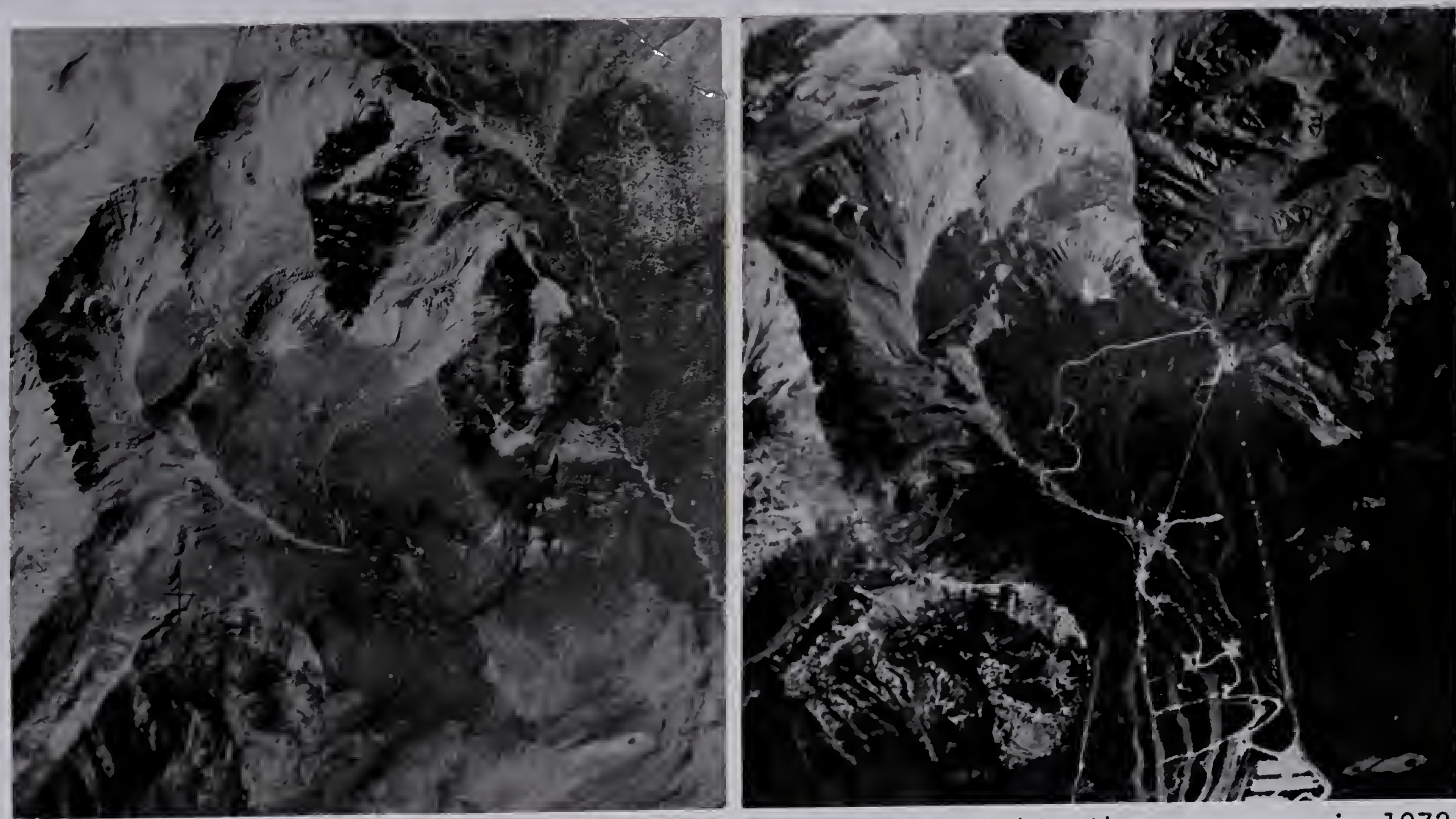


Plate 21. On the left, Marmot Basin in 1949 and on the right, the same area in 1972, after the development of ski facilities.

The removal of vegetation and soil has occurred: 1) on and along the access roads, 2) in the areas in which the ski lift terminals and the other buildings were constructed, and 3) in the sites where ski lift pillars were installed. The most extensive damage occurred at the top of Caribou Ridge, where the naturally sparse Rock Tundra vegetation was seriously disturbed during the construction of the Yellow T-bar and the Caribou Chair ski lifts (Plate 22).

Soil erosion has occurred in areas where the vegetation was removed and, in particular, at the top of the Caribou Ridge and along the main access road. Water and wind have removed most of the fine-textured soil in these sites, leaving only coarse gravel and rock.

Numerous vehicle tracks are evident in the wet meadow beside the main access road in the center of the basin. These tracks were probably made during the spring when the access road becomes very muddy and impassable, and vehicles were driven along the adjacent, somewhat drier terrain.

Some of the trees found on the ski slopes in the alpine were removed during the construction of the ski runs. Other trees have subsequently been damaged by machinery and skiers during the winter. Much more extensive tree removal operations occurred in the lower subalpine areas of Marmot Basin to allow for the construction of roads, buildings, parking lots, ski lifts and ski runs in these areas. All of the vegetation in the areas in which roads, buildings and parking lots were constructed was removed. In the upper subalpine, where trees are generally smaller and less frequent, and the understory is denser and more resistant to disturbance, much of the previously existing understory is still intact, although there are numerous bare spots,

Plate 22. The impact of the construction of roads, ski lifts and terminal buildings on the top of Caribou Ridge. (Fig. 3). The removal of plant cover in this area has led to erosion of the naturally thin soils. July 27, 1977.

where trees were removed which are still unvegetated. In the middle subalpine, where extensive removal of trees was carried out during the construction of ski runs and ski lifts, very little of the original understory remains. In most of these areas the land was bulldozed after the trees were removed to smooth out the slopes and grass was seeded to stabilize the soil.

Most of the impacts of the construction of ski facilities in the alpine zone of Marmot Basin could have been prevented if helicopters, such as were used in subsequent years to build the Knob Chair, had been used in building the Yellow T-bar and the Caribou Chair. Most of the impacts of the construction of these lifts were a result of the use of heavy machinery, which removed the sparse vegetation, thereby leading to soil erosion. There is very little damage of this type in the vicinity of the Knob Chair, although the vegetation there is also very sparse and susceptible to damage.

IMPACT OF WINTER SKI ACTIVITIES

The impacts of winter ski activities, including slope grooming and skier use, on the snow cover, vegetation and terrain of the heavily skied alpine zone of Marmot Basin (i.e. Slopes A, B & C, Fig. 3, p. 6) were assessed. Large tracked vehicles are used to compact the snow on the ski slopes during the winter. Packing is done both to prevent the snow from blowing away and to level the irregular hummocks and hollows or "moguls" that are formed on the ski slopes. These moguls are carved out of the snowpack by skiers. As skiers move downslope, they make a series of slalom turns which result in the redistribution

and compaction of the snow. Skiers and "packers" can also strip off the snow cover as they move over it, and expose the underlying vegetation and soil. The impact of skiers and slope grooming equipment on the terrain and vegetation, and in particular on *Cassiope mertensiana,* the most common species in the study area, was assessed.

SNOW COMPACTION

Snowpack

The results of the studies carried out at Marmot Basin in March and May, 1977, indicate that slope grooming and skier use during the preceding winter resulted in significant alterations in the depth, density and structure of the snowpack on skied slopes (Table 14). In March 1977, the snow on the skied side on Slope C had an average depth of 45 cm, while the snow on the non-skied side of Slope C had an average depth of 64 cm. The average density of the snow on the skied side was 0.39 gm/cc compared with 0.27 gm/cc on the non-skied side. By May, however, there was no difference between the depth of the snow on the skied and non-skied sections of Slope C, although there was still a significant difference between the density of the snow on the skied part (0.46 gm/cc) and the non-skied part (0.33 gm/cc) of Slope C. Ice layers were also found to be more prevalent in the skied snowpack than in the non-skied snowpack.

The results of the 1977 photoseries indicate that the compaction of the snow on the ski slopes did not result in any significant delay in the rate of snowmelt on skied terrain (Plates 23 to 27). The snow on the skied slopes actually melted more rapidly than did that found in non-skied areas.

TABLE 14. The depth and density of snow on skied and non-skied sides of of Slope C, in Marmot Basin, in March and May 1977.

SNOWPACK CONDITION	MARCH		MAY 1977	
	Skied	Non-Skied	Skied	Non-Skied
Average snow depth (cm)	45*	64	62	62
Average snow density (gm/cc)	.39	.27	.46	.33
No. of sites sampled (Two replicates per site)	14	18	46	56

*Pairs of underlined means are significantly different at the p = 0.05 level.

Terrain

A study was carried out in May, 1977, to determine if there was any difference in the temperature of the soil beneath the compacted snow on the skied slopes and the snow on the non-skied slopes. Results indicate that there was a strong correlation between both the depth and the water content (depth x density) of the snow and the temperature of the underlying soil (Fig. 15 & 16). Soil temperatures were the lowest in the areas in which the snow was the shallowest and had the lowest water content, and highest in the areas in which the snow was the deepest and contained the most water. There was no difference in the temperature of the soil under the snow on the skied compared with the non-skied slopes, in areas in which the snow was more than 60 cm deep.

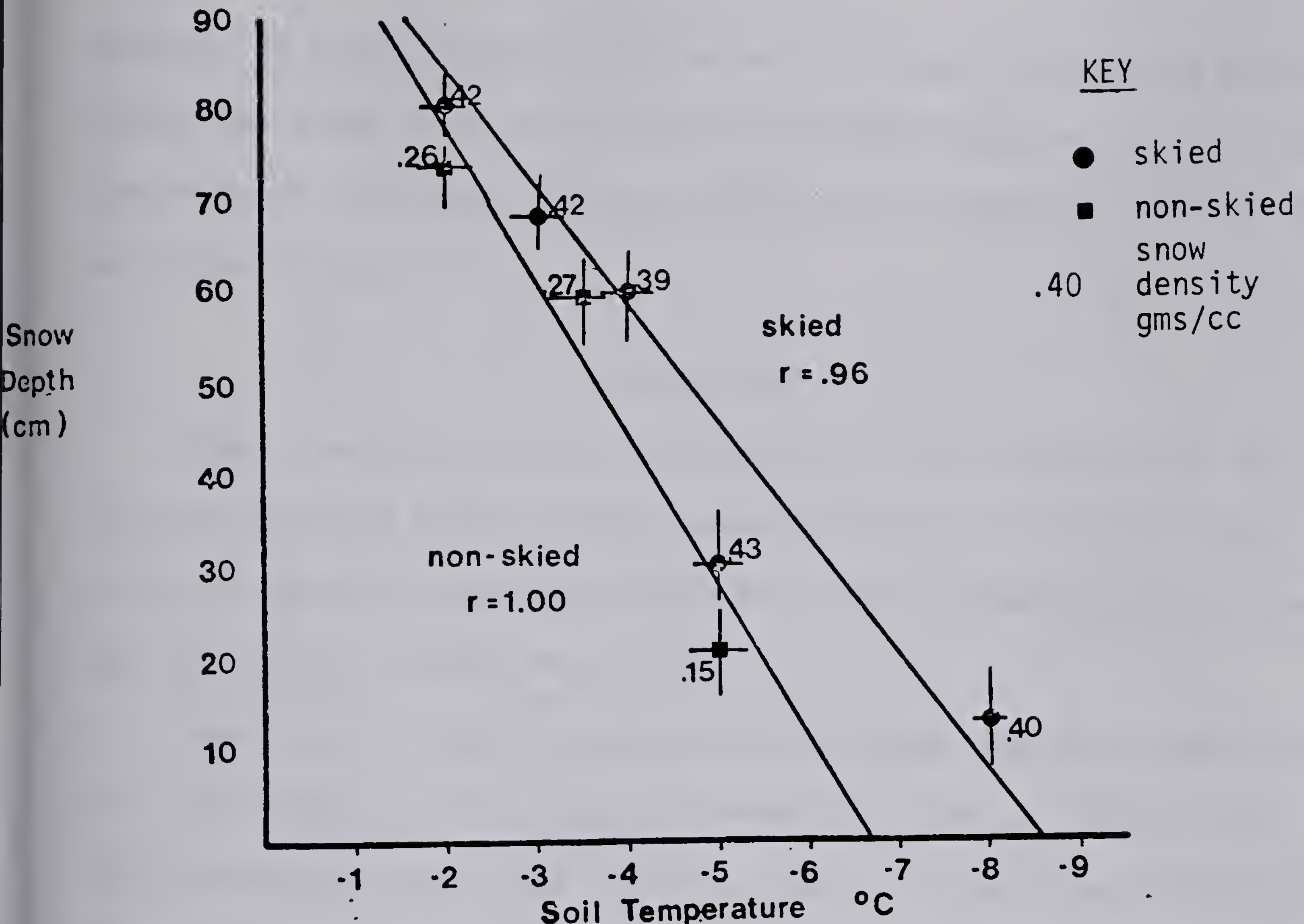


Fig. 15. The temperature of the soil found below snowpacks of varying depth and density.

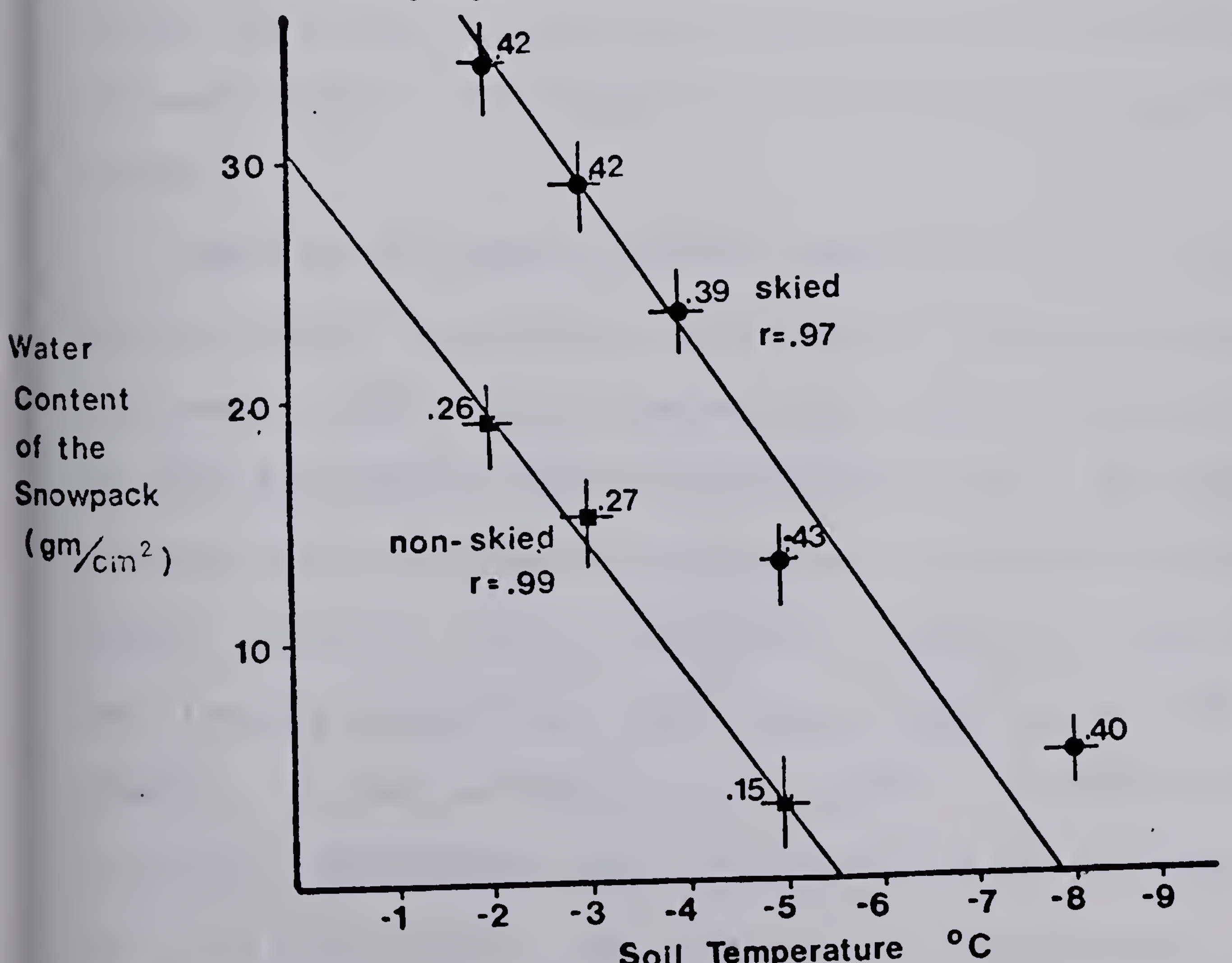


Fig. 16. The temperature of the soil found below snowpacks of varying water content and density.

However, in areas in which the snow was shallower, the snow on the skied slopes was found to be less effective in insulating the soil (i.e. soil temperatures were lower compared with areas of comparable depth on the non-skied slopes).

Vegetation

Studies were carried out to determine if the compaction of the snow on the skied slopes had any observable effects on the vitality (ratio of dead to live foliage) and the rates of phenological development of *Cassiope mertensiana* plants.

There was no significant correlation between the depth, density and water content of the snowpack during the winter of 1976-77, and the percentage of the total amount of *Cassiope mertensiana* foliage in the underlying site which was dead. This would indicate that the compaction of snow by skiers and machinery has not had any direct and observable impact on the vitality of the underlying *Cassiope mertensiana* plants.

There was no evidence that the compaction of snow on the skied slopes resulted in any delay in the onset of flowering or seed set in the summer of 1977. On the contrary, the *Cassiope mertensiana* plants on Slope A, a heavily skied section of Marmot Basin, were more advanced phenologically than those plants found on the non-skied sections of Slope C (Table 15). All of the *Cassiope mertensiana* plants on Slope A had already produced flower buds and were flowering, with 58% of the plants at the seed set stage by July 13, 1977. On the non-skied section of Slope C, approximately 10% of the plants had not yet budded, and only 2% of the plants had set seed by this time. The plants on Slope A,

which had been snow-released earlier, were more phenologically advanced than those on Slope C.

TABLE 15. Phenological status of *Cassiope mertensiana* plants in Marmot Basin, July 13, 1977.

PHENOLOGICAL STATUS	NON-SKIED SLOPE C	SKIED SLOPE A
Setting seed	2%	58%
Budding	89%	84%
Pre-budding	10%	0%
No. of sites sampled	61	31

SHEARING

Studies were carried out to determine the impact of the removal of snow cover by skiers and machinery. The specific impacts of this activity on the snowpack, terrain and vegetation were assessed. Results indicate that the shearing of the snow cover leads to: 1) accelerated snowmelt; 2) removal of plant cover and soil erosion; and 3) damage to the plants that are exposed by the removal of the snow cover.

Snowpack

A series of photographs were taken to document the rates of snowmelt on skied and non-skied slopes in 1977. Results of this study indicate that in both the alpine and subalpine zones of Marmot Basin heavily skied areas tend to melt-out before lightly or non-skied areas (Plates 23-27). Snow packing machines and skiers were found to shear off patches

Plate 23. Slope A on May 10, 1977. The presence of patches of exposed vegetation and soil on the skied slopes of Marmot Basin has resulted in accelerated snowmelt.

Plate 24. Slope A on June 5, 1977. Most of the snow in the heavily skied alpine and subalpine areas of Marmot Basin has melted by this date.

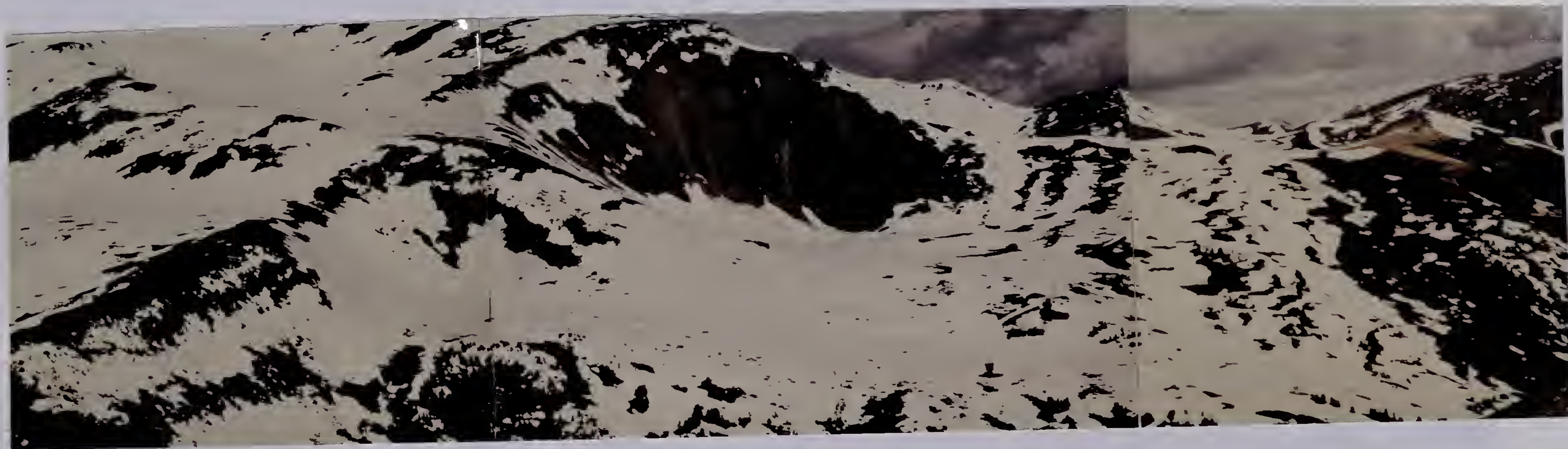


Plate 25. Photo no. 1 of a snowmelt series taken from Eagle Ridge in Marmot Basin, June 5, 1977.

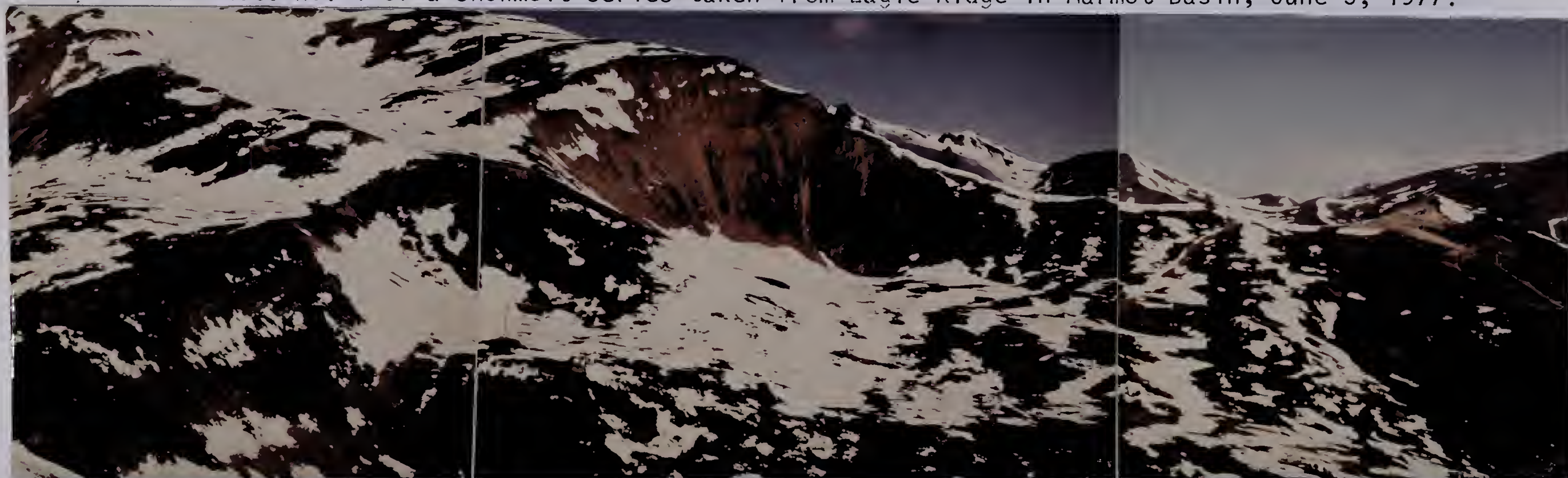


Plate 26. Photo no. 2 of a snowmelt series taken from Eagle Ridge in Marmot Basin, June 11, 1977.

Plate 27. Photo no. 3 of a snowmelt series taken from Eagle Ridge, Marmot Basin, June 20, 1977.

of the snow cover, exposing the underlying terrain. These darker areas of exposed soil have a lower albedo and therefore heat up, melting the surrounding snow. Snowmelt occurred most rapidly in areas which were heavily skied and also either on steep slopes or exposed to the wind and had a shallow snow cover; or had a southerly exposure and received more solar radiation which resulted in the melting of the existing snow cover.

Terrain

Approximately 6% of the terrain in the heavily skied sections of the alpine zone of Marmot Basin has been damaged (Table 16). Sheared ground is found only in convex, raised sites. Fifty percent of the terrain in the heavily skied parts of the alpine zones (Slopes A, B and C) was classified as convex; 11% of this convex terrain has been damaged by skiers and/or slope-grooming machinery. Approximately 3% of the convex terrain has been severely sheared and eroded, 3% has been sheared and frost-heaved ("churned"), while the remaining 3% was found to be sheared but had not yet become cryoturbated or eroded. Less than 0.5% of the damaged terrain showed evidence of regrowth. In most cases the patches of damaged ground were less than 1 m^2 in size. In 16% of the convex site plots the patches of damaged ground covered less than 5% of the m^2 plots. In 22% of the convex sites damaged ground covered 5-25% of the m^2 plots. Damaged ground covered 25-50% and 50-75% of the plots in 7% and 2% respectively, of the convex sites. Two percent of the convex plots were almost completely sheared (i.e. damaged ground covered 75-100% of the plot).

Table 16. The frequency, extent and severity of damage to terrain on heavily skied slopes in different parts of Marmot Basin.

	SLOPE A	SLOPE B	SLOPE C	TOTAL
TOPOGRAPHY				
Slope angle, average	26	16	7	
Slope aspect, average	E	SE	SSE	
Total number of 1x1 m plots	223	151	64	438
Number and frequency (%) of plots on convex terrain	123 (55%)	64 (42%)	31 (48%)	211 (50%)
IMPACT ASSESSMENT				
Number and frequency (%) of damaged plots on convex terrain	64 (52%)	29 (46%)	12 (39%)	105 (48%)
Total area (m^2) and relative area (%) of damaged plots on convex terrain	15 (12%)	4 (6%)	2 (6%)	21 (10%)
Total area (m^2) and relative area (%) of plots on convex terrain by impact classes				
eroded	6 (5%)	0.6 (1%)	0 (0%)	6.6 (3%)
churned	5 (4%)	2 (3%)	0 (0%)	7 (3%)
sheared	4 (3%)	1 (2%)	2 (6%)	7 (3%)
regrown	0.4 (0.3%)	0 (0%)	0.3 (1%)	0.7 (0.3%)
Number and frequency (%) of plots on convex terrain by % damage extent class				
0%	60 (49%)	34 (53%)	119 (61%)	113 (52%)
5%	6 (13%)	12 (18%)	7 (23%)	35 (16%)
5 - 25%	30 (24%)	14 (22%)	4 (13%)	48 (22%)
25 - 50%	11 (9%)	4 (6%)	0 (0%)	15 (7%)
50 - 75%	5 (4%)	0 (0%)	0 (0%)	5 (2%)
75 - 100%	4 (3%)	0 (0%)	1 (3%)	5 (2%)

Comparisons of values associated with Slopes A,B and C were made, underlined values are significantly different at the p=0.05 level.

Comparisons of the three heavily skied slopes (A, B and C) indicate that different levels of impact (i.e. frequency of shearing, areal extent of damaged ground, severity of damage and average size of patches of damaged ground) are found in different parts of Marmot Basin (Table 16). Approximately 29% of all sites on Slope A had been damaged compared with 19% of all sites on Slope B, and 19% of all sites on Slope C. Twelve percent of the convex terrain sampled on Slope A had been damaged, compared with 6% on Slopes B and C. There was significantly more eroded and churned ground on Slope A than on Slope B. No eroded or cryoturbated ground was found in any of the convex sites sampled on Slope C, although 6% of the ground in the convex sites had been sheared and was, therefore, susceptible to future erosion. There was no significant difference in the amount of regrowth found in the convex sites on Slopes A, B and C. A higher percentage of the convex sites on Slope C (61%) were undamaged compared with Slope B (53%) and Slope A (49%). Similarly, more of the plots of Slope C (23%) received only light localized damage (i.e. less than 5% of the plot was damaged), compared with Slopes A and B. A higher percentage of the plots on Slope A were more severely damaged compared to both Slopes B and C. Damaged ground covered a greater area and was more severely damaged on Slope A compared with Slope B and C. In most cases Slope B was intermediate in terms of impact, while Slope C had the least amount of damage.

These differences in the levels of damage found in the three areas may be attributed to differences in snow depth and skier use. Slope A is steeper (26^{o}), has a shallower snow cover and is more heavily used by skiers. Skiers using this steeper slope tend to make more frequent

turns which results in the shearing of the snow and ground cover. Slopes B and C are not as steep, 16^{0} and 7^{0} respectively, and have a thicker snow cover and are, therefore, not subjected to as much damage.

Vegetation

Studies were carried out to determine the impacts of the removal of snow by skiers and machinery on the underlying vegetation. Assessments of the extent and severity of shearing in the various plant communities found in the study area were made (Table 17). The impact of the removal of snow cover on the vitality (i.e. the percentage of the foliage which is dead) and flowering success of *Cassiope mertensiana* was investigated (Table 18).

The removal of the snow cover was found to result in damage to the underlying vegetation and, in particular, to the plant communities that occur on raised convex sites. Approximately 44-55% of the plots sampled in the *Dryas octopetala* - *Cassiope tetragona*, *Phyllodoce glanduliflora* - *Dryas octopetala* and *Phyllodoce glanduliflora* - lichen Rock and Heath Tundra communities, which occur in raised sites had been damaged. Thirty-one percent of the *Cassiope mertensiana* - *Phyllodoce glanduliflora* dominated Heath Tundra plots, which are found in faised, flat and concave sites were damaged. None of the 33 Heath Tundra plots dominated by *Cassiope mertensiana* or by *Cassiope mertensiana* and *Phyllodoce empetriformis* were damaged. These plots were usually concave.

Results indicated that the plants found on heavily skied, prematurely exposed, elevated convex sites had a significantly higher proportion of dead leaves (49%) than those which grew in more protected flat and concave sites (39% and 38% respectively) (Table 18). Shearing of the snow cover

Table 17. The frequency of damage to plant communities found on different types of terrain, on Slope A, Marmot Basin.

COMMUNITY TYPE	TERRAIN* TYPE	NUMBER AND FREQUENCY (%) OF DAMAGED PLOTS		
1. *Dryas octopetala - Phyllodoce glanduliflora*	Cx	8 (50%)	n† = 16	+
6. *Phyllodoce glanduliflora - Dryas octopetala*	Cx	7 (47%)	n = 15	+
6. *Phyllodoce glanduliflora*	Cx	4 (44%)	n = 9	+
7a. *Cassiope mertensiana - Phyllodoce glanduliflora*	Cx, F, Cv	15 (31%)	n = 48	
7. *Cassiope mertensiana*	Cv	0 (0%)	n = 24	+
7e. *Cassiope mertensiana - Phyllodoce empetriformis*	Cv	0 (0%)	n = 9	+

*Cx = convex, F = flat, Cv = concave
† no. of sample plots
+ bracketed values are not significantly different (p=0.05), based on the t-test.

TABLE 18. Percent cover of *Cassiope mertensiana* foliage which was dead on concave, flat and convex skied terrain on Slope A.

TERRAIN TYPE	PERCENT COVER OF DEAD *Cassiope mertensiana* FOLIAGE		
Convex	49 %	n* = 104	
Flat	39 %	n = 70	+
Concave	38 %	n = 67	+

*n = number of sample plots
+ bracketed values are not significantly different (p=0.05), based on the t-test.

by skiers and machinery results in the earlier snow-release of the plants found in the convex sites. It appears that this may either directly or indirectly result in a loss of plant vitality.

In the subalpine zone of Marmot Basin there was significantly more dead *Cassiope mertensiana* foliage on the ski runs than there was in the adjacent forests.

The *Cassiope mertensiana* plants which grew on the skied slopes that are snow-free earlier in some years than the adjacent non-skied areas were more phenologically advanced than the plants which grew on non-skied slopes (Table 15, p.116).

REVEGETATION

Studies were carried out to determine the success of natural revegetation on sites disturbed by construction and ongoing skier use.

Natural revegetation was found to have occurred in sites disturbed during the construction of ski facilities. Some regrowth of graminoid seedlings was found along the sides of roads on abandoned roadways and around the pillars and terminal buildings of the ski lifts (Plate 22, p.110). Revegetation is most successful in sites which have been left undisturbed.

Some seeding of the sites disturbed during construction has occurred (e.g. around the ski lift pillars). Assessments of the vitality of this vegetation, made in August 1978, indicate that the seeded grasses have established themselves fairly successfully. Further monitoring would be required before the success of this revegetation program could be evaluated.

Monitoring of plots with sheared terrain was also done to determine if natural revegetation of these localized bare spots would occur (Plates 28-34). In areas that had only been superficially sheared, such that the soil remained intact, regrowth by vegetative expansion of herbaceous plants and plants with rooting branches such as *Salix arctica* was found to occur. Slow growing heath species were not found to revegetate as rapidly.

In the subalpine where fairly extensive disturbance of the vegetation on the ski slopes occured (i.e. removal and burning of trees, and exposure of large patches of soil), several weedy species such as *Epilobium angustifolium* (fireweed) are found revegetating disturbed sites.

The most severe erosion in the alpine is found along the roads and in the vicinity of the terminal buildings. Water from melting snow, and to some extent wind, have removed much of the mineral and organic fines from the upper soil horizon in these sites. Localized erosion is found in areas which were severely sheared by skiers and packing machinery (Plate 28-30). This type of erosion is especially prevalent in sites that are exposed to meltwater runoff (Plate 30). Further monitoring of these plots to assess the erosion and regrowth potential of sheared sites is ongoing.

Plate 28. Two Rock Tundra sites in Marmot Basin where shearing of the ground cover has occurred. In the left photo regrowth of the damaged vegetation has occurred in some of the bare patches. In the right photo, erosion of the exposed soil has taken place.

Plate 29. Permanent plot no.1 on June 7, 1977. This plot which is located in a *Salix arctica-Dryas octopetala* Shrub Tundra community, was sheared during the preceding winter.

Plate 30. Permanent plot no. 1 on August 8, 1977. Some of the soil which was exposed during the summer has eroded, while in other parts of the plot there has been some regrowth of the surficially sheared vegetation.

Plate 31. Permanent plot no. 5 on June 7, 1977. Surficial shearing of the *Cassiope tetragona* dominated vegetation found in this plot, has occurred.

Plate 32. Permanent plot no. 5 on August 8, 1977. There has been little erosion of the exposed soil in this plot. Some regrowth of *Salix arctica* plants has occurred.

Plate 33. Permanent plot no. 35 on June 7, 1977. The upper layer of soil has been disturbed in this *Dryas octopetala* - *Cassiope tetragona* dominated plot.

Plate 34. Permanent plot no. 35 on August 8, 1977. Limited erosion of the exposed soil has occurred. Some regrowth by *Salix arctica* appears to be occurring in this plot.

CHAPTER VIII. DISCUSSION: IMPACT ASSESSMENT

During the construction of ski resorts, various facilities including roads, buildings and ski lifts are built. Throughout the ski season snow-packing machines and skiers compact the snow cover on the slopes. Snow compaction may lead to: 1) alteration in the insulative capacity and, therefore, in the thermal regime of the underlying vegetation (Neumann and Merriam 1972, Wanek 1975); and 2) alteration of natural snowmelt patterns (Watson *et al.* 1970, Larcher *et al.* 1975, Fitzmartyn 1976). In addition to compacting the snow, skiers and heavy machinery can also cause redistribution of the snow cover and exposure of the underlying terrain (Watson *et al.* 1970). This may lead to acceleration of natural snowmelt. A study was carried out in the alpine zone of Marmot Basin to determine: 1) what effect the construction of ski facilities had upon the area and, 2) what effect winter ski activities had upon the snowpack, terrain and vegetation.

IMPACT OF CONSTRUCTION

Studies previously carried out in downhill ski areas and other alpine areas indicate that the construction of facilities including access roads, buildings, parking lots and ski lifts cause appreciable

damage to the environment (Watson *et al.* 1970, Klock 1973, Fitzmartyn 1976). At Marmot Basin the most observable impacts of ski development on the alpine zone are those associated with the construction of access roads and ski lifts (Table 19, Plates 21 & 22). Roads were built to Caribou Ridge to facilitate the building of both the Yellow T-bar and the Caribou Chair. The construction of these roads resulted in the removal of plant cover and erosion of the soil in the vicinity of the roads, terminal buildings, and the ski lift pillars. Much of this impact could have been reduced had helicopter construction been utilized in the construction of the Yellow T-bar and the Caribou Chair lifts. The use of helicopters in the construction of the Knob Chair in Marmot Basin and other ski lifts in alpine areas (Watson *et al.* 1970) reduced the environmental impacts of this type of construction.

Other ski area construction activities, including the removal of ground cover, the clearing of trees to make ski runs in forested areas, and bulldozing the terrain to remove stumps, have resulted in extensive damage in other ski areas (Muir 1967, Klock 1973, Fitzmartyn 1976, Bayfield 1976). Although terrain modification and tree removal has been carried out in the subalpine zone of Marmot Basin, these operations were not necessary in the alpine where there are, by definition, very few trees. There has, consequently, been considerably less impact due to construction in the alpine zone of Marmot Basin than in either the subalpine zone of Marmot Basin, or in most other subalpine ski areas. In Mission Ridge, Washington (Klock 1973), where extensive removal of plant cover and terrain modification was done, severe soil erosion has occurred.

Table 19. Summary of the effects of ski area construction, winter ski activities and similar activities upon the snow pack, terrain and vegetation found in alpine areas.

EFFECT ON:	SKI AREA CONSTRUCTION	WINTER SKI AND RELATED ACTIVITIES							
		Mechanical Damage			Snow Compaction				
		Snow Packers and Skiers Shearing	Trampling	Grazing	Snow Packers and Skiers	Snow-mobiles	Snow Roads	Snowpack Augment-ation	Natural delay
SNOW									
Increased Density					*1,*2,*3,*5	*10,*9	*11		
Loss of Insulative Capacity						*10,*9	*11		
Accelerated Snowmelt		*1							
Delayed Snowmelt					*2,*3,*5	*10,*9	*11		
VEGETATION									
Altered Growth-Form	+3							*6	*7
Change in Floristic Composition									
-Introduction of Weedy Species	*1,*2			*14					
-Loss of Native Species						*10			
Change in Community Structure			*12	*14	*5	*10			*7,*8
Change in Vigor									
-Delayed in Flowering						*10			*7,*8
-Decreased Flowering Success			*12	*14	+2	*10			
-Decreased Productivity			*12 *13		+2,+3				
TERRAIN									
Removal of Ground Cover	*1,*2,*3, *4,*5	*1,*2,*3	*13						
Erosion	*1,*2,*3, *4,*5	*1,+2,*3							

*Evidence that impact is caused by this agent
+Speculated that impact is caused by this agent

INVESTIGATORS
SKI AREAS
1. Marmot Basin, Alberta
2. Sunshine, Alberta - Muir 1967, Leeson 1976, Fitzmartyn 1976
3. Cairngorm Scotland - Watson *et al.* 1970
4. Mission Ridge, Washington - Klock 1973
5. Mt. Patscherkofel, Austria - Larcher *et al.* 1975

SNOWPACK AUGMENTATION
6. Webber 1976

NATURAL SNOWPACKS
7. Weaver 1974
8. Holway and Ward 1965

SNOWMOBILING
9. Neumann and Merrian 1972
10. Wanek 1975

SNOW ROADS
11. Inuvik Snow Road 1974

TRAMPLING
12. Willard and Marr 1970, 1971
13. Bell and Bliss 1976

GRAZING
14. Reich 1976

The construction of ski facilities in the alpine zone at Marmot was found to have had the greatest impact on the Rock Tundra vegetation near the tops of ridges where terminal buildings were built, and in the Meadow Tundra areas traversed by vehicles during the construction phase. The susceptibility of this alpine tundra group will be discussed in the following section.

IMPACT OF WINTER SKI ACTIVITIES

Studies were carried out at Marmot Basin to determine what effects winter ski activities, including skier use and slope grooming, have on the alpine ecosystem, and especially on the snowpack and the underlying terrain and vegetation. These studies included assessments of: 1) the direct effects of the compaction and removal of the snow cover by the skiers and machinery on the snowpack, and 2) the secondary effects of snowpack alterations on the underlying vegetation and terrain.

SNOWPACK

Studies at the Sunshine ski area in Banff National Park indicate that compaction of snow on skied slopes results in a significant increase in snow density and in the formation of ice layers in the snow (Table 19). Similar physical changes in the snowpack on skied slopes were found at Marmot Basin. However, no appreciable decrease in the depth of snow on packed vs. non-packed slopes was found in the spring of 1977 (Table 14).

Further investigations were made to determine if there was any difference between soil temperatures beneath the packed snow on the

skied slopes and the unpacked snow of similar depth on the non-skied slopes. The temperatures at the soil surface will be influenced by the thermal conductivity of the overlying snowpack. The thermal conductivity of snow is proportional to its density (Formosov 1946). Since densely compacted snow is a poor insulator, one would expect to find lower soil temperatures beneath the denser snow on the skied slopes on cold days. Neumann and Merriam (1972) reported abnormally low temperatures beneath dense snow when the air temperature was below $0^{o}C$. In addition to causing greater extremes in soil temperatures, one would expect to find more frequent temperature fluctuations beneath more densely compacted snow (W. Moser, pers. comm.).

No significant differences were noted between the temperature of the soil beneath snow of similar depth but different density in March, 1977, at Marmot Basin (Fig. 15). However, the lowest soil temperatures were consistently found in sites that had a thin, dense snow cover. Snow density and depth are both important in determining the soil temperature when snow depths are shallow. The increased density of the snow on the skied slopes may result in significant alteration of the soil thermal regime in the winter when snow depths are not at maximum, as they are in the spring. Similarly, the compaction of snow in sites that naturally have a thin snow cover may have a significant effect on the thermal regime of that site throughout the year.

Further monitoring of sites with varying depths of snow cover on skied and unskied terrain would be required to determine the overall impact of snow compaction on the insulative properties of the snow and the thermal regime of the underlying soil. Additional studies would

be required to assess the impact on vegetation of any alteration of the soil thermal regime.

Studies were done to determine if the compaction and shearing of snow cover on skied slopes had a significant effect on the rates and patterns of snowmelt.

Results of similar studies at Sunshine by Fitzmartyn (1976) suggested packed snow on the skied slopes would melt more slowly than the non-packed snow (Table 21). Delays in the melting of the snow on skied slopes also occurred in Austria (Larcher *et al.* 1975) and in Scotland (Watson *et al.* 1970). Denser snow has been shown to melt more slowly than uncompacted snow (Wanek 1975). Therefore, the snow on the ski slopes might be expected to remain longer than that on non-skied areas. In addition, the presence of ice layers found in the compacted snow on ski slopes would be expected to delay meltout; Langeham (1974) showed that the retention of meltwaters above ice layers in a snowpack resulted in delayed melt.

Although the packed snow on the skied slopes at Marmot was generally more dense and contained more ice layers than the unpacked snow and would therefore be expected to melt more slowly than the non-packed snow, the photoseries taken in the spring of 1977 (Plates 23-24) indicates that there was no delay in the melting of snow on skied slopes that year. On the contrary, much of the skied terrain was snowfree before the non-skied terrain. The occurrence of accelerated snowmelt on skied slopes is further documented by the results of the phenological survey. This indicated that there is no delay, but rather an acceleration of the phenological development of key tundra plant species on the skied cf. non-skied slopes.

The presence of patches of bare soil and exposed vegetation caused by the shearing of the snow cover by skiers and machinery help to accelerate snowmelt on skied slopes. Once the snow cover is removed from a site and the underlying terrain exposed, melting of the surrounding snow proceeds rapidly, since darker patches absorb more radiation, warm faster and can supply heat to melt the snow. Since numerous patches of bare soil were found on the ski slopes of Marmot Basin in 1977, acceleration of snowmelt occurred there in the spring. This type of exposure of soil and vegetation has been found to occur in other ski areas including Sunshine (Fitzmartyn 1976) and Cairngorm, Scotland (Bayfield 1970). The accelerated snowmelt on heavily skied terrain would be expected to occur in these areas as well.

The accelerated snowmelt observed in 1977, occurred after a spring of below average snowfall (Table 2, p. 23). This snowmelt pattern was not evident in the following year (1978) after a spring of more normal snowfall. The depth of the snow cover appears to be of prime importance in determining of shearing of the snow cover and, therefore, snowmelt acceleration are to occur.

In summary, the most significant effects of winter ski activities at Marmot Basin on the snowpack are: 1) increased snow density, and 2) increased frequency of ice layers and 3) alteration in the snowmelt patterns on the skied slopes. Alteration of snowmelt was caused by the removal of patches of snow cover by skiers, thus exposing the underlying soil. The long-term implications of these changes cannot be adequately assessed at this time. These impacts would probably be of greatest significance in areas that have a low or highly variable winter snow cover.

TERRAIN

Snow compaction has been shown to result in the alteration of the thermal regime of the soil, which underlies compacted snowpacks. The potential impacts of altered soil temperatures on the vegetation found on ski slopes will be discussed in the next section.

The removal of sections of the snow cover by skiers and machinery results in the exposure of the underlying soil to further damage. Damage to the terrain caused by skiers and grooming equipment has been reported in other ski areas including Cairngorm, Scotland (Watson *et al.* 1970) and Sunshine (Fitzmartyn 1976). Watson *et al.* (1970) found that machinery caused severe shearing of the terrain on ski slopes, while skiers usually caused light to moderate damage. At Marmot Basin in 1976-77, shearing of the snow cover and subsequent damage to the terrain appeared to be caused primarily by skiers.

The degree to which skier use results in shearing of the snow cover and accelerated snowmelt on ski slopes is determined by many factors, the most important being the depth of the snow base on the skied slopes. As previously mentioned, winter weather conditions determine to a great extent the depth of snowpack and, therefore, the extent to which shearing of the snow cover and subsequent exposure of the terrain will occur. In years such as 1977-78, when spring snowfall was normal, there was little or no shearing of the snow cover and terrain on the skied slopes and, therefore, no acceleration in snowmelt. In 1976-77, spring snowfall was quite low and the snow base on the ski slopes was thin and readily sheared. Frequent shearing of the snow cover and terrain occurred that year.

Shearing of the snow cover and underlying terrain is most likely to occur when snow depths are shallow, the snow is soft and shears readily, and/or skier use is heavy. Generally, the snowpack is the thinnest in the fall before much snow has fallen on the slopes. By the end of the ski season, however, numerous areas of shallow snow will be present where successive passes of skiers and machinery have removed the snow cover. Most of the damage resulting from shearing of the snow cover and terrain is thought to occur in the spring when the snow is soft and readily sheared (Watson *et al.* 1970), and skier use is heavy.

The highest levels of impact at Marmot Basin occurred in the areas that had a relatively shallow snow cover. The depth of the snow cover in an area is dependent on several factors, including: 1) amount of precipitation received, 2) elevation, 3) exposure to wind, 4) slope aspect, 5) slope angle, and 6) microtopography. These factors can be used to predict the susceptibility of a site to shearing damage. At Marmot Basin the shallowest snow cover and the highest levels of shearing were found in sites that were on steeply sloping, exposed, E-facing slopes that had irregular microtopography. Less damage was found at sites on more gently and smoothly sloping, wind-protected, N-facing slopes.

These factors determine both the amount of snowfall received and retained in a site. More snow is retained on higher elevation, protected, gently sloping, concave sites than on lower elevation, windswept, steeply sloping, convex terrain. Slope aspect is important in determining the amount of solar radiation received by a site and, therefore, the rates of snowmelt.

VEGETATION

The effects of winter ski activities on the underlying vegetation were examined. Results were used along with additional information on the physiology of the plant species found in the study area to predict the susceptibility to and potential effects of winter ski activities on the vegetation of Marmot Basin.

Snow Compaction

Other studies have indicated that the compaction of snow reduces its insulative capacity, resulting in lower soil temperatures and reducing the vitality of the underlying vegetation (Wanek 1975) (Table 19). Comparisons of the vegetation on skied and non-skied slopes of Marmot Basin were made to assess and predict the effects of snow compaction on alpine vegetation.

Although resulting in some increase in snow density, the packing of snow on ski slopes was generally found to have little effect on the insulative capacity on the snow in the spring. There were no significant differences in the temperatures of the soil beneath the skied and non-skied slopes, nor were there any observable differences in the vitality and/or flowering success of *Cassiope mertensiana* found on skied and non-skied slopes. No significant correlations between snow depth, density and the vitality of the underlying *C. mertensiana* could be found.

Most alpine plants, including *Cassiope mertensiana*, normally experience both cold temperatures as well as fluctuation in the depth and density of winter snow cover. In most cases, the compaction of snow

on ski slopes results in snow densities that are within the range of those normally found in alpine snowpacks (Alford 1967). Therefore, it is not likely that changes in the snow's insulative capacity caused by snowpacking would have a significant effect on the underlying vegetation. In some areas, however, where the natural snow cover is shallow, snow compaction was found to result in snow densities that were considerably higher than those normally found in non-skied areas. In addition, the compaction of snow earlier in the year, when snow cover is generally quite thin, would probably result in an appreciable alteration in the normal thermal regime of the vegetation beneath the packed snow. Further monitoring of temperatures of the soil beneath snow of varying depths and densities would be required to predict the effects of snow compaction on the underlying vegetation.

Removal of Snow Cover

Snowmelt alteration

Winter ski activities significantly alter the rate of snowmelt on the skied slopes in some years. Studies were made to determine if this change had an appreciable effect on the vegetation on the ski slopes.

The primary effect of accelerated snowmelt is the exposure of the alpine vegetation to harsh spring conditions. These plants are usually under the snow at this time of the year and are protected from the extremes and fluctuations in temperature which occur in the spring (Bliss 1969). Plants exposed in the spring are susceptible to desiccation injury when the soils are frozen and the plants are actively transpiring. Premature snowmelt may also result in drought conditions later in the summer. The water from melting snowbanks is a vital source of moisture

for many alpine plants in the summer when rainfall is often light and/or infrequent, and evapotranspiration potentials are high (Janz and Storr 1977). Without the moisture supply provided by melting snowbanks, many alpine plants would experience moisture stress and potential injury.

The accelerated snowmelt would likely have the most serious effects on species that could not tolerate prolonged moisture stress conditions. Chionophilous species such as *Cassiope mertensiana* that normally have a deep, moderately late-melting snow cover would be expected to be affected by accelerated snowmelt.

Estimates of the cover of dead *Cassiope mertensiana* on early cf. later snow-released sites (i.e., convex *vs* concave terrain) were used as estimates of the health of the species in these sites. This information was used to assess the potential effects of premature snowmelt on *C. mertensiana.*

Significantly higher ratios of dead to live *Cassiope mertensiana* foliage were found in the earlier snow-released, convex sites. This may be due to the fact that plants in these sites are exposed to greater moisture stress, a condition to which *Cassiope mertensiana* is poorly adapted (Tranquillini 1964). Natural reductions in snow cover have been observed to result in high levels of mortality in *Cassiope mertensiana* growing at lower elevations in the Coastal Mountains of B.C. (Brink 1959). Studies of a similar heath species, *Calluna vulgaris*, indicate that when exposed to the combination of high evapotranspiration and frozen soil conditions, its foliage will "winter brown" and subsequently turn grey (Watson *et al.* 1966). This phenomenon seems similar to that which is occurring in *C. mertensiana* at Marmot Basin.

Although continuous occurrences of accelerated snowmelt could potentially have a detrimental effect on *Cassiope mertensiana*, comparisons of the *Cassiope mertensiana* found on skied cf. non-skied sites in the alpine zone in Marmot Basin indicate that there was no difference in the amount of dead foliage found on skied cf. non-skied slopes. Although quantitative studies were not done in the subalpine, it was evident that the *C. mertensiana* plants on the prematurely snow-released skied subalpine slopes were in poorer health than those in the non-skied sites. This may be attributable to the more frequent occurrence of premature snowmelt on subalpine ski runs. Here snow cover is generally thinner since less snow falls at these lower elevations. Ski runs are narrower than in the alpine and, therefore, use of these runs is quite intensive. Premature snow-release would probably occur more frequently in these areas than in the alpine where the snow base is generally deeper and there are not distinctive ski runs making for less intensive use of any part of the slope.

The lack of observable differences in the ratio of dead to live foliage on the skied cf. non-skied alpine areas may also indicate that any changes in plant vitality that occur as a result of accelerated snowmelt do not have an immediate effect on the amount of dead foliage. Since there have not been many low snow years such as 1977 (Table 2 , p. 23), in which accelerated snowmelt would probably have occurred in the alpine, it is possible that any effects of this change are not yet apparent and may be evident only after several years in which early snowmelt occurs. The overall effect of successive years of accelerated snowmelt on the vegetation of an alpine region would probably be the decrease in

vitality and abundance of chionophilous species, and a corresponding increase in the vitality and abundance of chionophobous species. This phenomenon is thought to have occurred in some of the *Cassiope mertensiana* communities on convex sites in heavily skied areas. In these sites, where much of the *Cassiope mertensiana* is dead, there has been an increase in the importance of the subdominant species, including *Salix arctica*, that have a wider range of tolerances. These *C. mertensiana* communities appear to be changing and becoming more similar to Shrub Tundra communities normally found in earlier snow-released sites. If continued for many years, accelerated snowmelt would lead to a decrease in the areal importance of communities dominated by chionophilous species such as *C. mertensiana* and an increase in the extent of chionophobous communities.

Plant species found in Rock Tundra communities are adapted to early snow-release conditions and would probably be tolerant of accelerated snowmelt conditions. The plants in these communities are normally covered by only a thin snow layer in the winter and are subject to a wide range in snowmelt dates. Once snowfree, the soils in these exposed sites dry up rapidly. Since these species normally experience conditions similar to those caused by accelerated snowmelt, they would not be expected to be adversely affected by this change.

Shrub Tundra communities dominated by *Salix arctica* and *Artemisia norvegica*, both fairly ubiquitous species in Marmot Basin, would also be predicted to increase in importance since these species have a wide range of tolerance.

Heath Tundra communities dominated by *Phyllodoce glanduliflora*, a species which commonly occurs in sites that are snowfree fairly early,

would also become more prominent. Communities dominated by *Cassiope mertensiana*, a chionophile, would tend to decrease in importance. Meadow Tundra requires a supply of water throughout the summer, and may be adversely affected by the more xeric late summer conditions that would occur as a result of accelerated snowmelt. Snowbed Tundra species would probably not be able to compete successfully with the other species that would be able to invade the snowbeds, if accelerated snowmelt extended the growing season. Snowbed species such as *Carex nigricans* might be able to colonize nivation hollows, decreasing the extent and frequency of the latter.

Although there was no evidence that the compaction of snow on the ski runs at Marmot Basin in 1977 led to delayed snowmelt, studies done at Sunshine (Fitzmartyn 1976) suggest that such delays can occur. Although not found in 1977, a year of below average snowfall, delayed snowmelt may occur in the skied slopes at Marmot in years when snowfall is higher. The effects of delayed snowmelt on the vegetation of Marmot Basin could be predicted on the basis of other studies on the effects of delayed snowmelt on alpine vegetation.

One of the primary effects of delayed snowmelt is a shortening of the length of the growing season (Holway and Ward 1965). Delayed snowmelt also results in the retention of cold meltwaters later in the summer than would normally occur. This in turn results in the maintenance of low soil temperatures during the summer. This change in environmental conditions would favour those species which are adapted to late snowmelt conditions.

For most species delayed snowmelt would result in retarded development, failure to complete their life cycle, and ultimate replacement by other more chionophilous species (Holway and Ward 1965). Snowbed Tundra communities which experience a very short growing season would be most susceptible to damage resulting from delayed snowmelt (i.e. reduced productivity and flowering success (Webber 1976). Fitzmartyn (1976) has reported decreased flowering success in herbaceous plants on ski slopes at Sunshine, a condition potentially caused by delayed snowmelt. Rock Tundra communities which normally experience a wide range of snow release dates would not be as seriously affected by delayed snowmelt (Webber 1976).

The overall effect of delayed snowmelt would be a change in the composition and productivity of communities, favouring the increased vigour of chionophilous species and areal extent of Snowbed Tundra. In areas presently occupied by Snowbed Tundra, delayed snowmelt may shorten the growing season to such an extent that plant survival is impossible. In this case, the plants in these sites would die out and these areas would become nivation hollows.

Mechanical Damage

Studies were carried out to assess the type, severity and extent of damage caused by shearing to the plant communities of Marmot Basin. Results of this study can be used to predict the susceptibility of these plant communities to mechanical damage.

Rock Tundra communities suffered the most frequent and severe damage. Heath Tundra communities dominated by *Phyllodoce glanduliflora* were less frequently sheared, and there was virtually no removal of the ground cover in the *Cassiope mertensiana* dominated communities (Table 20).

Table 20. The susceptibility of tundra community Groups found in the alpine zone of Marmot Basin to damage by ski activities and the potential for recovery.

	TUNDRA COMMUNITY GROUP				
	Rock Tundra	Shrub Tundra	Heath Tundra	Meadow Tundra	Snowbed Tundra
A. SUSCEPTIBILITY OF:					
1. Habitat to Shearing	*				
(i) Depth of Snowcover	Shallow[9,12]	Moderate[9]	Moderate-deep	Deep[15]	Very deep[8]
(ii) Terrain Type	Convex	Variable	Variable	Variable	Concave
Rating	High	Moderate	Moderate	Low	Low
2. Vegetation to Damage Once Exposed					
(i) Height of Vegetation	Short	Short-Tall	Moderate	Moderate-Tall	Short
(ii) Predominant Growth Form	Dwarf Shrub	Deciduous Shrub	Evergreen Shrub	Forb-Graminoids	Graminoids
(iii) Reported Level of Damage of Comparable Forms by					
- grazing				Moderate[13]	Low[13]
- trampling	Moderate[2,15]	High[8]-Moderate	High[7,15]	High[15]	Low[2,7,15]
- snowmobiling		High[14]	High[14]		
Rating	High	Variable	High	High	Moderate
3. Soils to Erosion Once Exposed					
(i) Type of Soil	Thin Regosolic[9]	Variable	Thick Brunisolic[9]	Thick Brunisolic[9]	Thick Gleysolic[9]
(ii) Density of Roots	Low	Variable	High[15]	High	High
(iii) Exposure to Erosive Agents					
- wind	High	Variable	Low	Low	Low
- water	Moderate	Variable	Moderate	High	High
Rating	High	Variable	Low	Moderate	Moderate
B. POTENTIAL FOR RECOVERY					
1. Potential for Revegetation by					
(i) Vegetative Reproduction	Good[3]	Good[3]	Good[1]		Good
(ii) Seedling Establishment	Low[11,4]	Low[4,11]	Low[4,11]	Low[4,11]	Low[4,11]
2. Growth Rates	Slow[10,15]				Slow[3]
Rating	Low	Moderate	Moderate	Moderate	Low[13]

*

1. Bayfield 1970
2. Bell and Bliss 1973
3. Billings 1971
4. Bonde 1968
5. Broad 1973
6. Brink 1964
7. Campbell and Scotter 1974
8. Holmes *et al.* 1976
9. Knapik *et al.* 1973
10. Kuchar 1975
11. Osburn 1961
12. Ogilvie 1976
13. Reich 1976
14. Wanek 1975
15. Willard and Marr 1971
16. Zwinger and Willard 1972

The severity and extent of damage to a community are strongly related to winter snow cover depth and terrain type. Exposed convex sites had a shallower snow cover and were, therefore, more readily damaged than protected concave sites. Since there is also a close relationship between the depth of the winter snow cover, type of terrain and the type of plant community found in a site, one also finds a close predictable relationship between the amount and severity of shearing and the type of plant community found in a site.

The amount of exposed soil in a community is dependent to some extent on the nature of the vegetation and its resistance to shearing damage. Communities that consist of tall woody plants that are not readily sheared off will have less exposed soil than communities consisting of more fragile species.

High levels of impact were found in the Rock Tundra communities on the skied slopes at Sunshine (Fitzmartyn 1976) and Marmot Basin. The winter snow cover in these exposed convex sites is thin and readily sheared off, exposing the underlying vegetation to further damage and removal. The most common plants in the Rock Tundra sites, including *Dryas octopetala* and *Salix nivalis,* are of low stature, such that complete removal of the snow cover in a site has to occur before these plants would be exposed and damaged (Table 20). Since, however, the snow cover in these areas is normally quite thin, exposure of the underlying vegetation might be expected to occur quite frequently. Once snowfree, dwarf shrubs such as *Dryas* and *Salix nivalis* are susceptible to mechanical injury and removal. Willard and Marr (1970) rated low growing plants such as these as moderately susceptible to mechanical

damage caused by trampling. Once shearing of the plant cover occurs, natural revegetation by these species occurs quite slowly. Although these dwarf shrubs have adventitiously rooting stems that facilitate vegetative reproduction (Porsild 1974), the severity of the environment in Rock Tundra sites allows only very slow growth rates (Kuchar 1975) and therefore slow revegation of disturbed sites. Insufficient information on the success of seedling establishment in Rock Tundra habitats is available to enable prediction of the potential for natural revegetation from a nearby seed source, should much of the *Dryas octopetala* and *Salix nivalis* in a site be removed. Several workers, including Osburn (1961) and Bonde (1968), found that successful plant establishment from seed is not common in alpine tundra.

Once the plant cover is removed from Rock Tundra dominated sites, the soil is susceptible to frost heaving (Brink 1964), resulting in the disruption of the upper soil horizon. Since the soils in these sites are thin (Knapik *et al.* 1973) and the plants inhabiting these sites do not have a dense root mat (Porsild 1974), the soils are quite susceptible to erosion. Wind and water would remove the mineral and humic fines once the plant cover was removed. This erosion of the upper soil horizon, leaving only the coarse materials, has been found to occur in many disturbed sites in Marmot Basin.

At Marmot Basin the Heath Tundra communities dominated by *Phyllodoce glanduliflora* received moderately frequent shearing (Table 17, p.124). The winter snow cover in these sites is deeper than that in the Rock Tundra sites and, therefore, is not as readily removed (Table 17). Woody species such as *Phyllodoce glanduliflora* and *Salix arctica*, both

common in this community, are reported to be susceptible to mechanical damage (Wanek 1975). Results of this study indicate that shrubby species such as *Salix arctica* will regrow readily in areas that were only superficially sheared such that the underground rhizomes are left intact. Since *Salix arctica* has freely rooting branches (Porsild 1974), revegetation of bare spots by neighbouring plants would also be expected to occur. The rates of regrowth in these more mesic Heath Tundra sites would be faster than those in the more xeric habitats occupied by Rock Tundra vegetation. The thick Brunisolic soils in *Phyllodoce glanduliflora* dominated sites are more resistant to erosion than the thin Regosolics found in more exposed areas. In general, *Phyllodoce glanduliflora* Heath Tundra communities appear less susceptible to damage and recover more rapidly after damage than the communities in more exposed sites.

Moderate levels of impact were found in those *Cassiope mertensiana* - *Phyllodoce glanduliflora* communities which occurred on convex and level terrain in heavily skied sections of Marmot Basin. There was virtually no shearing of plant cover in the *Cassiope mertensiana* - *Phyllodoce empetriformis* communities found in concave sites that had a deeper snow cover (Table 17). The differences in the frequency of bare patches is attributable to the differences in habitats in which two communities occur rather than to differential resistances of the plants to shearing.

Once exposed, plants such as *Cassiope* and *Phyllodoce* are quite susceptible to mechanical damage (Wanek 1975). Complete removal of the relatively dense plant cover and exposure of the underlying soil does not occur frequently. Provided any areas of exposed terrain found in these communities are small and only superficially sheared such that

the soil remains intact, revegetation of these sites by the lateral growth of neighbouring plants should occur.

Once complete removal of the ground cover and disturbance or exposure of the soil occurs, erosion is almost certain to follow. The physical properties of the soils and the frequency of exposure of a site to erosive forces are important in determining the rates of erosion. If erosion occurs very slowly and plant regrowth occurs rapidly, the new vegetation may stabilize the sheared sites and curtail severe damage. The turfy soils in Heath Tundra communities are fairly resistant to erosion. These sites are not subjected to the erosive forces of runoff water and wind to the extent that the Rock Tundra communities are. In general, Heath Tundra communities are less likely to be damaged and better able to recover from superficial damage than most of the other alpine communities.

Neither the Meadow Tundra nor the Snowbed Tundra communities at Marmot Basin were appreciably damaged by skiers or packing machinery. This is attributable to the fact that these communities are generally small in size, not common in heavily skied areas, and usually occur in sites that have a deep winter snow cover and are, therefore, protected from shearing. However, Meadow and Snowbed Tundra at Marmot have been damaged by summer activities. Vehicle tracks occur throughout the wet meadow sites close to the main access road.

If exposed to shearing, the forbs and graminoids commonly found in these communities would be expected to be removed quite readily. Regrowth, especially of the graminoids, known to be tolerant of removal by grazers (Reich 1975), would be expected to occur fairly readily. Forbs

are less tolerant of clipping and would not recover as rapidly. Graminoids have been noted to be the most successful colonizers of disturbed sites in the study area. These species are probably the best adapted for natural revegetation of disturbed areas. If the plant cover is removed from Meadow or Snowbed Tundra communities erosion would occur. Although Meadow Tundra soils are thick and have a dense root mat, the presence of meltwater channels through these sites would tend to erode them. Meadow and Snowbed Tundra communities would not, in general, be tolerant of disturbance, and if damaged, would be subject to appreciable erosion.

CHAPTER IX. IMPLICATIONS AND PREDICTIONS

MANAGEMENT IMPLICATIONS

FUTURE DEVELOPMENT

It is evident that the development of ski facilities does have a significant effect on alpine ecosystems of the northern Rocky Mountains. Decisions to proceed with or limit this type of development in the National Parks should be made, cognizant of the long-lasting and long term effects.

The effects of construction and ski activities on alpine ecosystems in Marmot Basin have been examined and compared with those found elsewhere. Even so, some of the potential effects of ski activities can only be speculated upon at this time. More research would be required to determine the long term effects of such practices as snow compaction and shearing on the vegetation and terrain.

Should it be decided to allow further ski development in Marmot Basin, these points should be considered:

1) Site Location

(a) Although this study focused on the impact of skiing in the alpine zone, observations on the impact found in the subalpine

zone were made. In general, tree removal and terrain modification to create ski runs through subalpine forests caused more damage to the vegetation than changes made in the alpine zone. In this respect, alpine areas appear more suited for ski area development. However, the sensitive nature and slow recovery rates of disturbed tundra vegetation weigh against development in the alpine zone.

(b) In alpine areas selected for ski development, the damage caused by shearing will be less significant in areas with a heavy and consistent winter snowpack. Therefore, sites with shallow snowcover should not be used for skiing within any ski resort area. Terminal buildings, at the top of ski lifts in particular, should not be built in thinly snow-covered, Rock Tundra areas. They can cause appreciable loss of both snow and plant cover by channelling and concentrating large numbers of skiers into a sensitive area. In addition to being the most susceptible to damage, Rock Tundra vegetation regrows very slowly. If used, extensive snow fences would be required.

(c) Although shearing damage should be least in deep snowpack sites, the impact of snow compaction (i.e., loss of insulative capacity and delayed snowmelt) will be greatest in these sites. In view of the high erodability of severely damaged Meadow and Snowbed Tundra communities, construction of ski facilities should be avoided in these sites.

In view of the preceding points, it may be concluded that sites with moderate snow cover and more resistant Heath Tundra vegetation, as

prevail at Marmot Basin, would appear to be best choices for ski development.

2) Construction Methods

Much of the initial impact associated with the construction of ski facilities could be avoided if helicopters were used in the construction of lifts. In addition to eliminating the need for roads, air-access construction greatly reduces the loss of ground cover around terminal buildings and pillars.

EXISTING FACILITIES

The impact of shearing of snow, plant cover and terrain in existing ski sites can and should be minimized by carefully monitoring their snow depths and restricting their use when the snow cover is too thin or unstable (e.g., in the fall and spring).

PREDICTIONS

1. Since the Knob Chair had not been constructed prior to the initiation of this study, there was no skiing impact in that part of the study area. However, results of this study indicate that much of the terrain near the top of this lift is occupied by Rock Tundra (Fig. 14) that is both very susceptible to damage and slow to regrow. It is, therefore, predicted that significant damage will occur near the top of the Knob Chair lift.

2. Much of the terrain in Marmot Basin is concave in profile, has a deep winter snow cover, and has not been adversely affected by shearing. Some sites, e.g. around the tops of Knob, Caribou and the Yellow T-bar lifts, are convex in profile, heavily used by skiers, have a thin winter snow cover, and may thus become more severely damaged in the future.
3. Natural revegetation will probably occur in sites that have been only superficially and not repeatedly sheared, such that the plant cover and soil remain intact. Revegetation of sheared sites in Rock Tundra communities will likely occur only very slowly. More rapid revegetation will probably occur in environmentally more favourable Heath and Meadow Tundra dominated areas.
4. Erosion will probably continue in sites that have been sheared severely. Once eroded, revegetation will not occur readily, if at all.
5. Artificial revegetation by seeding was found to produce a lush herbaceous cover in sites around the pillars of the lifts. The long-term success of this revegetation project cannot, however, be assessed at this time.

CHAPTER X. SUMMARY

PLANT COMMUNITIES

1. The alpine vegetation of Marmot Basin is typical of high snow accumulation areas in the northern Rocky Mountains. The plant communities found at Marmot include most of the range of communities found in the alpine zone of the Rocky Mountains in Alberta.
2. Two Heath Tundra community types form the dominant ground cover: *Cassiope mertensiana* communities occur in protected, late snow-released, mesic sites; *Phyllodoce glanduliflora* communities occur in better-drained, more exposed sites.
3. Rock Tundra communities dominated by *Dryas octopetala* occur in exposed convex sites that have a thin winter snow cover and are snow-free early in the summer.
4. Shrub Tundra communities are found in a variety of moderately early snow-released sites.
5. Lush Forb dominated Meadow Tundra communities occur in wet, seepage sites.
6. Sparse graminoid dominated Meadow Tundra communities occur on steep, unstable scree slopes and on disturbed sites.

7. Snowbed Tundra communities dominated by *Carex nigricans* and *Antennaria lanata* are found in late snow-released sites.
8. The distribution of plant communities in Marmot Basin is controlled primarily by snow-release date and site moisture regime. These environmental variables are correlated such that early snow-released sites are usually xeric, and late snow-released sites are usually hygric.

IMPACT ASSESSMENT

9. The most obvious impact of construction of ski facilities at Marmot Basin was the removal of the vegetation from ski runs in the subalpine. This has resulted in erosion and a loss of plant vitality.
10. In alpine areas where extensive tree removal was not required, the most obvious impact of ski area construction has been the building of roads, shelters and ski lifts. This construction has resulted in loss of plant cover and soil erosion.
11. Winter ski activities, including skier use and motorized snow packing, had a significant effect on snowpack, terrain and vegetation in alpine and subalpine zones.
12. The primary impact of winter ski activities on the snowpack was the acceleration of snowmelt caused by removal of the snow cover which exposed the underlying terrain.
13. Snow packing and skier use also increased snow density and ice layer frequency on skied slopes and thereby potentially altered the thermal regime of the underlying vegetation and soil.

14. The alteration of snowmelt may cause shifts in community distribution and phenology, and decreased vigour of alpine plants not adapted to abnormally earlier or later snowmelt conditions if these conditions occurred repeatedly.
15. Shearing of the ground cover is most likely to occur in low snowfall years in early winter when snow cover is thin or in the spring when snow is soft and easily removed.
16. Higher levels of foliage mortality were found in the *Cassiope mertensiana* plants which occurred on convex cf. concave sites. This may be attributable to mechanical injury and/or early spring exposure to desiccation.
17. Soil erosion occurred in severely sheared sites. In superficially damaged sites, regrowth of the natural vegetation occurred. Rates of regrowth are controlled by the microclimate of the site.
18. Rock Tundra communities found on thinly snow-covered sites were the most susceptible to damage, most prone to erosion and slowest to revegetate. Heath Tundra communities found in deeply snow-covered mesic, concave sites received considerably less shearing. These sites were less likely to erode and more rapid to revegetate. Meadow and Snowbed Tundra communities are usually found in deep, snow-covered, protected sites and, therefore, are not subject to shearing. If severely damaged, however, these sites would likely erode.

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CHAPTER XII. APPENDIX

VASCULAR FLORA OF THE ALPINE REGION OF MARMOT BASIN

ANGIOSPERMAE
MONOCOTYLEDONAE

GRAMINEAE

* *Agropyron latiglume* (Scribn. & Smith) Rydb.
* *Agrostis variabilis* Rydb.
* *Danthonia intermedia* Vasey
* *Deschampsia atropurpurea* (Wahlenb.) Scheele
* *Festuca brachyphylla* Schultes
* *Hierochloe alpina* (SW.) R. & S.
* *Phleum alpinum* L.
* *Poa alpina* L.
* *P. arctica* R. Br.
* *P. epilis* Scribn.
P. leptocoma Trin.
P. pattersonii Vasey
P. pratensis L.
* *Trisetum spicatum* (L.) Richter

CYPERACEAE

Carex albo-nigra Mack.
C. deflexa Hornem.
C. festivella Mack.
* *C. nigricans* C.A. Meyer
C. phaeocephala Piper
* *C. spectabilis* Dewey
C. stenochaeta (Holm) Mack.
C. pyrenaica

JUNCACEAE

* *Juncus drummondii* E. Meyer
* *Luzula spicata* (L.) DC
* *L. Wahlenbergii* Rupr.
L. piperi M.E. Jones

DICOTYLEDONAE

SALICACEAE

* *Salix arctica* Pall.
* *S. Barrattiana* Hook.
* *S. nivalis* Hook. (*S. reticulata* spp. *nivalis* Love, Love and Kapoor)

POLYGONACEAE

Oxyria digyna (L.) Hill
* *Polygonum viviparum* L.

PORTULACEAE

* *Claytonia lanceolata* Pursh.

CARYOPHYLLACEAE

* *Minuartia rubella* (Wahlenb.) J.E. Sm.
M. sajanensis Willd.
* *Silene acaulis* L.
Stellaria crassifolia Ehrh.
* *S. ruscifolia* Pall ssp. *alentica* Hult.

RANUNCULACEAE

* *Anemone occidentalis* S. Wats.
A. parviflora Michx.
Caltha leptosepala DC.
* *Ranunculus eschscholtzii* Schlecht.
* *Trollius albiflorus* (A. Gray) Rhdb.

CRUCIFERAE

Arabis lyallii S. Wats.
Cardamine bellidifolia L.
C. umbellata Greene
Draba stenoloba Ledeb.

CRASSULACEAE

* *Sedum stenopetalum* Pursh.

SAXIFRAGACEAE

Parnassia fimbriata Konig
Saxifraga bronchialis L.
S. cernua L.
S. lyallii Engler
S. rhomboidea Greene

ROSACEAE

* *Dryas octopetala* L.
* *Luetkea pectinata* (Pursh) Kuntze
* *Potentilla diversifolia* Lehm.
P. hyparctica Malte
* *P. nivea* L.
P. uniflora Ledeb.
P. vahliana Lehm.
* *Sibbaldia procumbens* L.

EMPETRACEAE

Empetrum nigrum L.

ONAGRACEAE

* *Epilobium alpinum* L.
E. angustifolium L.
E. latifolium L.

VIOLACEAE

Viola glabella Nutt.

ERICACEAE

Arctostaphylos uva-ursi (L.) Spreng.
* *Cassiope mertensiana* (Bong) D. Don
* *C. tetragona* (L.) D. Don ssp. *saximontana* (Small) Porsild
* *Phyllodoce empetriformis* (Smith) D. Don
* *P. glanduliflora* (Hook.) Coville
Vaccinium caespitosum Michx.
* *V. scoparium* Leiberg
V. vitis-idaea L. var. *minus* Lodd.

GENTIANACEAE

* *Gentiana glauca* Pallas
Gentianella propinqua (Richards.) J.M. Gillett

SCROPHULARIACEAE

Castilleja miniata Dougl.
* *C. occidentalis* Torr.
Pedicularis arctica R.Br.
* *P. bracteosa* Benth.
* *Veronica alpina* L. var. *unalaschensis* C. & S.

CAMPANULACEAE

* *Campanula lasiocarpa* Cham.

VALERIANACEAE

* *Valeriana sitchensis* Bong.

COMPOSITAE

Achillea millefolium L.
Agoseris aurantiaca (Hook.) Greene
* *Antennaria alpina* (L.) Gaernt. var. *media* (Greene) Jepson
* *A. lanata* (Hook.) Greene
* *Arnica cordifolia* Hook.
A. diversifolia Greene
A. latifolia Bong.
A. mollis Hook.
* *Artemisia norvegica* Fries
* *Erigeron peregrinus* (Pursh) Greene subsp. *callianthemus* (Greene) Cronq.
* *Hieracium gracile* Hook.
Petasites frigidus (L.) Fries var. *nivalis* Cronq.
Senecio pauciflorus Pursh.
* *S. triangularis* Hooke.
* *Solidago multiradiata* Ait.

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* Species used in Ordinations

Fig. 14. Map of the vegetation of the alpine zone of Marmot Basin.

Key

- Subalpine forest - continuous
- Subalpine forest - discontinuous, krumholz trees
- Heath Tundra mosaic - predominantly *Cassiope mertensiana* communities
- Heath Tundra - *Phyllodoce glanduliflora* communities
- Shrub Tundra - *Artemisia norvigica* communities
- Shrub Tundra - *Salix barrattiana* communities
- Meadow Tundra - predominantly communities of the Forb Meadow Subgroup
- Snowbed Tundra - *Carex nigricans* communities
- Snowbed / Shrub Tundra mosaic - predominantly *Carex nigricans* and *Salix nivalis* communities
- Rock Tundra - *Dryas octopetala* and *Cassiope tetragona* communities
- Rock / Snowbed Tundra mosaic - predominantly *Dryas octopetala* and *Antennaria lanata* dominated communities
- Scree slopes - including *Luzula wahlenbergii* communities of Graminoid Meadow Subgroup
- Disturbed areas - roads, ski lifts and terminals, buildings

1 Stand numbers